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ABSTRACT

A study examined the actual and projected impact of automation on employment between 1963 and 2000. Utilizing a fully integrated, dynamic input-output model that was designed for this study, the researchers analyzed a large body of quantitative information from diverse, especially technical, sources. This effort resulted in the development of a detailed model of the probable effects of automation on the demand for labor services in 53 occupations. According to this model, the intensive use of automation over the next 20 years will make it possible to conserve about 10 percent of the labor that would have been required to produce the same bills of goods in the absence of increased automation. The impact of automation is specific to different types of work and will involve a significant increase in professionals as a proportion of the labor force and a steep decline in the relative number of clerical workers. Because the direct displacement of production workers by specific items of automated equipment will, at least in the initial stages, be offset by increased investment demand for capital goods, production workers can be expected to maintain their share of the labor force. (MN)

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THE IMPACTS OF AUTOMATION ON EMPLOYMENT, 1963-2000

Final Report

by

Wassily Leontief and Faye Duchin

with Daniel Szyld, Jesus Alvarez, David Howell, Michel Juillard,
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Abstract

Issues. There is no doubt that computers and computer-based automation will have far-reaching effects on the U.S. economy and society. There is a broad range of views in the scholarly literature and popular press about the nature and extent of these effects. Government policies, however, should and can be based not on opinion, but, so far as possible, on concrete, detailed analysis of the probable impacts of the impending technical changes. Only action based on such anticipation will be able to reduce the individual and social costs that belated adjustments to unanticipated structural shifts will entail.

Methodology. This study incorporates a large body of quantitative information from diverse, especially technical, sources into an input-output model of the U.S. economy to draw a comprehensive and internally consistent picture of the progressive introduction of computers and of various forms of computer-based automation into 89 individual industries comprising the entire economy. It spells out in great detail the probable effects of these technological changes on outputs and inputs of all goods and services and in particular on the demand for labor services described in terms of 53 different occupations. These projections are based on four alternative scenarios about future technological change.

A fully integrated, dynamic input-output model, developed for this study, provides the analytical framework for capturing not only the direct but also the indirect effects of all these changes. In particular it takes into account the effects of technological change on the investment requirements of all the different sectors and the corresponding changes in the outputs of capital goods producing industries.

Findings. The intensive use of automation over the next twenty years will make it possible to conserve about 10% of the labor that would have been required to produce the same bills of goods in the absence of increased automation. The impacts are specific to different types of work and will

involve a significant increase in professionals as a proportion of the labor force and a steep decline in the relative number of clerical workers. Production workers can be expected to maintain their share of the labor force; direct displacement by specific items of automated equipment (like robots and numerically controlled machine tools) will, at least in the initial stages, be offset by the increased investment demand for all sorts of capital goods, especially computers.

Computations that assume the full utilization of the projected future labor force suggest that personal and government consumption will be able to increase about 2% a year in real terms through the 1980's and between 0.5 and 1.1% through the 1990's due to the adoption of computer-based automation (in the absence of other structural changes). Whether or not the smooth transition from the old to the new technology can actually be realized will depend to a large extent on whether the necessary changes in the skill structure of the labor force and its distribution between different sectors of the economy (and geographic locations) can be effectively carried out. The study projects the direction and magnitude of these changes in the structure of the labor force and of the educational and training efforts needed to carry them out.

Preface

The following inquiry is concerned with the complex issues surrounding the changing structure of employment in the U.S. in the recent past, and especially in the future two decades. A team of about ten researchers collaborated closely in this effort over a period of three years. Because of the emphasis in this study on change, it was indispensable to develop a disaggregated dynamic input-output model of the economy capable of absorbing detailed information on technological change.

Voluminous historical data had to be assembled for testing and refining the performance of the model over the past two decades. Even more challenging was the fact finding task of extracting from a great variety of published and unpublished sources detailed estimates of the input-output structure of computerbased production processes that can be expected to be adopted in the different sectors of the U.S. economy in the course of the next two decades. A large number of methodological issues had to be settled in connection with the systematic representation of technological change.

Such work will eventually entail direct use of detailed engineering and management planning information. This level of effort was not possible in the present study, and it proved to be necessary to rely to a great extent on piecing together different and often differing expert estimates. Such future work will have to examine in detail technological change specific to each individual sector. This study concentrated instead, as a first step, on the changes that can be anticipated in many sectors; these changes are described in considerable detail within the report.

The principal investigators attempted to provide enough direction to ensure the compatibility of many individuals' contributions while tolerating and even encouraging differences of point of view and approach in an area that is still virtually uncharted. The following chapters describing this work provide ample evidence of this precarious balance. While they have been extensively reworked and edited, individual authorship is unmistakable.

Professor Leontief, Director of the Institute for Economic Analysis, provided overall direction for this research. The conduct of the study was supervised by Dr. Faye Duchin, Associate Director of the Institute. Her efforts were in particular concentrated on the formulation of a new dynamic input-output model, more realistic than its many predecessors, and the continual methodological integration and evaluation of the data bases and projections as well as aligning and editing of separate chapters.

A crucial role was played by Dr. Daniel Szyld, mathematician and programming expert, who collaborated in the formulation of the dynamic input-output model and coauthored Chapter 2 with Dr. Duchin. In addition to supervising the computations, he assured the completeness and consistency of the data provided by other colleagues and their compatibility with the requirements of the model.

The many sets of data produced by government agencies were assembled and prepared to meet the requirements of the model with meticulous attention to detail by Messrs. Jesus Alvarez and Michel Juillard, a visiting scholar supported in part by the Swiss government, who together prepared Chapter 3 describing that work.

Dr. David Howell was responsible for the qualitative description and quantitative projections regarding the use of computers and computer-based automation in production operations in all sectors of the economy. He describes and documents this work in Chapter 4.

Ms. Catherine McDonough and Glenn-Marie Lange carried out sector studies regarding the future use of computers in other applications. In Chapter 5, Ms. McDonough describes the process of office automation. Ms. Lange's work on the education and health care sectors is presented in Chapters 6 and 7, respectively, and in Chapter 8 she describes the projections of deliveries to final demand.

Mr. Dimitri Turchin was responsible for implementing and maintaining the database and the computer model and carried out most of the computations. He was assisted with the computations at different periods by Messrs. Kenneth Furlong, Vladimir Roytman, and Oleg Vishnepolsky.

Ms. Mary Parker organized the assembly and processing of the manuscript and, along with Dr. Szyld, provided extensive editorial assistance. Most of the processing was done by Ms. Holly Lammers.

While it is satisfying to have completed what has been a long and intense research effort, in fact it represents just the beginning of the systematic investigation of a complex and important subject. We have benefited, in preparing this report, from comments elicited by the Draft Final Report. We are well aware of the preliminary nature of our findings. Each of us naturally assumes the responsibility for our own contribution to the study. The principal investigators are responsible for the conclusions.

W. Leontief
F. Duchin

The Impacts of Automation on Employment, 1963-2000

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List of Abbreviations

BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
CBI	Computer-Based Instruction
CFT	Capital Flow Table
E&D	Eating and Drinking Places
IEA	Institute for Economic Analysis
IEA #nn	Sector number nn in the IEA sectoral classification scheme
IO	Input-output
ITV	Instructional Television
LAB #mm	Occupation number mm in the IEA occupational classification scheme
NC(CNC)	Numerically Controlled (Computer Numerically Controlled)
nec	not elsewhere classified
NIPA	National Income and Product Accounts
OA	Office Automation
SIC	Standard Industrial Classification

Chapter 1. The Impacts of Automation on Employment, 1963-2000

A. Introduction

The opinions expressed in the scholarly literature as well as the popular press cover a wide range, from reassurance that declining rates of growth of the labor force in the 1980's and 1990's will more than compensate for any loss of jobs to predictions that the manufacturing labor force will fall from over 25 million now to less than 3 million by 2010. We are told that some jobs will become more technical and complex than ever but also about the prospects for a "deskilled" workforce of sweepers and button-pushers. Most observers agree about painful "adjustment" and the needs of retraining, often in the context of measures to ease the "transition" to some automated future which remains entirely unspecified.

Barely beneath the surface of these debates, there are passionate social, political, and philosophical differences. An additional cause of confusion is that we cannot carry out a "factual" analysis, if that means direct observation, of the future. In this report, we develop and illustrate a fact-finding and modeling approach that promises to be fruitful in the dispassionate analysis of these issues. After ascertaining the operating characteristics of the already existing, newly developed types of computer and computer-based equipment, we proceed to derive the consequences of alternative assumptions concerning future rates of introduction into the different industries. Taking into account the corresponding changes in the combination of other inputs, particularly labor inputs, we insert the appropriate figures (combinations of so-called technical input coefficients) into a dynamic input-output model and use it to trace the direct and indirect effects of these technical changes on the future levels of output and input--particularly labor inputs--throughout all sectors of the economy.

While there is no shortage of "expert" estimates of isolated numbers (like the sales of computers in 1990), the specialized literature in this area is still very limited, and robotics seems to be the only aspect of automation that has been studied at all systematically to date. While technical studies like those that have so far been carried out only for robotics must be welcomed and encouraged, their detailed findings need to be incorporated with the results of other similar studies into a comprehensive analytical framework before useful general conclusions can be drawn. It is precisely such an effort, based on a dynamic input-output model of the U.S. economy, that is described in this report.

A number of other studies of structural change have been carried out within the input-output framework, starting with Professor Leontief's analysis in the 1930's of the changing U.S. economy between 1919 and 1929 [Leontief, 1941]. Most other empirical work has also been concerned with analysis of the past, notably [Carter, 1970; Vaccara and Simon, 1968; Bezdek and Wendling, 1976]. The formulation of detailed scenarios[1] to analyze future prospects was also initiated by Leontief [Leontief, Carter, and Petri, 1977]. A recent input-output study of the impacts of future technological change on the Austrian economy involving construction of alternative scenarios follows in this tradition [Osterreichisches Institut, 1981]. The Economic Growth Model of the Bureau of Labor Statistics (BLS) uses an input-output module within an econometric framework to project future employment [U.S. Department of Labor, 1982b]. We have made extensive use of the historical data prepared by this group, directed by Ronald Kutscher, in the development of our model. We have also used their detailed projections of final demand.

Alternative technological scenarios are formulated and computed within the framework of a comprehensive, dynamic input-output model of the entire U.S. economy developed for this study. This means that inter-temporal consistency is assured between the production of investment goods and their subsequent availability. The level and composition of each sector's annual replacement and expansion investment reflect within the framework of this model the particular technological and growth conditions postulated in each scenario.[2] The data work carried out for this study, although still very far from exhaustive, is more comprehensive and more fully documented than that used in most other descriptions of the U.S. economy, especially with regard to future technological options, and the alternative scenarios are designed so as to focus attention on intensive examination of the changing structure of employment.

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[1] "Scenario," in the narrow sense, means a set of assumptions about certain aspects of the economy. When the implications of the scenario are computed, projections of other aspects of the economy are obtained. The word is also used to mean the projections implied by the assumptions.

[2] The World Model [Leontief, Carter, and Petri, 1977] took some steps in these directions: all the other cited studies were carried out essentially within a comparative static framework.

It needs to be emphasized at the outset that this study represents only a first step in anticipating the future demand for labor. In addition to the preliminary nature of the work that has been done, we have concentrated on only one--albeit the newest, most talked about--component of technological change: computer-based automation. Our most substantial results will be based on the comparison of employment projections under alternative assumptions about computer-based automation. While some readers may be tempted to draw more general conclusions about future technological unemployment, such an analysis cannot be supported by the work which has been done to date. This is one of our next tasks.

The report is divided into four parts. Part I provides an overview of the study and reports the results. The dynamic input-output model is described in Part II. Part III describes the assembly of the database for 1963 to 1980, and the five chapters of Part IV contain sector studies on the automation of production and office operations, education, and healthcare which serve as the basis for alternative scenarios about the future. The Appendix contains the graphic presentation of selected results under alternative scenarios.

B. Methodology and Scenarios

To improve the understanding of the impacts of past technological change on employment in the U.S. and to assess the probable effects of impending computer-based automation the demand for labor over the next few decades, a dynamic input-output model of the U.S. economy was developed and an extensive database was prepared containing descriptions of past and present technologies and of technological changes to be introduced in the relatively near future. Four different scenarios were formulated, and alternative projections based on them were computed with the model to determine the structure of employment corresponding to each of them. This section provides an overview of the methodology and describes the scenarios. A formal description of the model and data used in its practical implementation is provided in the following chapters.

The national economy consists of a set of inter-related sectors each characterized at a given time by a common principal output and the combination of inputs to produce that output--including labor inputs of various types. The establishments in each sector employ in any given year a specific mix of machines, tools, and human labor to transform a specific combination of purchased inputs (produced by the same or other sectors) into the characteristic output of the sector.

At any given time there are typically several distinct technologies or production processes in use at different establishments within a sector or even at a single plant.

The average combination of inputs that characterize the sector corresponds to both the input requirements of alternative technologies and the weight with which each alternative operates in the national economy. Technological change involves a change in these weights, where typically the newest technologies are progressively phased in (increased weight) and the oldest eliminated (decreased weight). Of course, technological change also involves the introduction of new processes and products that were not previously available.

Portions of a sector's stock of plant and equipment are periodically replaced while current additions to it make possible an increase of output in the future. The technological requirements for the replacement of existing capital (i.e. to maintain current production capacity) are in large part dictated by the mix of investment goods already in place and to this extent reflect the technologies already in use. Some modernization also takes place; this involves the incorporation of newly available technologies into existing plant. However, in a growing economy the new technologies are typically reflected first in newly produced capital equipment installed expressly for the expansion of existing capacity-- and naturally in the occupational composition of the labor force which works with the physical capital and other inputs.

The state of the national economy in each year over the time interval 1963-2000 is described in terms of commodity flows among 89 producing sectors and labor inputs absorbed by each of them specified in terms of 53 occupations.

Numerical data are organized for each year into four matrices of technical parameters describing the input structures of all sectors of the economy during that year. These matrices specify the input requirements on current account (A matrix), capital expansion and replacement requirements (B and R matrices, respectively), and labor inputs (L matrix), of each sector per unit of its respective total output--or per unit of projected future increase in capacity in the case of expansion. Vectors of non-investment final demand, including household consumption, government purchases, and net exports (y vector) are also required. For the past years, government agencies produce official series containing most of this information: the sources and data preparation are described in Chapter 3.

Figures describing future technological options are assembled as part of separate sector studies which appear in Chapters 4-8. These sector studies yielded descriptions of alternative input structures, that is, columns and rows of technical coefficients that are inserted into the A, B, R, and L matrices. They also yielded projected vectors of non-investment final demand (y), for future years. The fact-finding efforts were concentrated on the systematic study of computers used to automate production and office operations, as well as the potential for automation in the education and health care sectors. Figure 1.1 indicates the rows and columns of coefficients, including capital and labor coefficients, which have been re-examined.

In addition to this data base, the structure of the model

Figure 1.1. Location of the 1980 Technical Coefficients
Re-Examined for Projections to 1990 and 2000

A, B, and R Matrices

IEA #	Sector		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1-4	Agriculture	1																	x	x	x			x								x	x	
5-10	Mining	2																	x	x	x			x								x	x	
11	Construction	3																	x	x	x			x								x	x	
12	Ordnance	4																	x	x	x			x								x	x	
13,14	Food, etc.	5																	x	x	x			x								x	x	
15-18, 32,33	Textiles, etc.	6																	x	x	x			x								x	x	
19-25	Lumber, Paper, etc.	7																	x	x	x			x								x		
26-28, 31	Chemicals, etc.	8																	x	x	x			x								x	x	
29	Paints	9				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x	
30	Petroleum Refining	10																	x	x	x			x								x	x	
34,35	Glass, Stone, Clay	11																	x	x	x			x								x	x	
36	Iron and Steel	12				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x	
37	Nonferrous Metals	13																	x	x	x			x								x	x	
38-41	Metal Products	14																	x	x	x			x								x	x	
46	Metalworking Machinery	15				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x	
42-45, 47-49, 52	Other Machinery	16																	x	x	x			x								x	x	
86	Robots	17				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x	
50	Computers	18	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
51	Office Equipment	19	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
53-55, 60	Electrical Equip., etc.	20																	x	x	x			x								x	x	
56	Communications Equip.	21																	x	x	x			x								x	x	
57-59	Electronic Components	22																	x	x	x			x								x	x	
61-63	Transportation Equip.	23																	x	x	x			x								x	x	
64-66	Other Manufacturing	24																	x	x	x			x								x	x	
67, 71, 72	Transp. and Trade	25																	x	x	x			x								x	x	
68, 69	Communications	26																	x	x	x			x								x	x	
70	Utilities	27																	x	x	x			x								x	x	
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77	Business Services	29																	x	x	x			x								x	x	
81, 82	Health Care	30																	x	x	x			x								x	x	
83, 87-89	Education	31	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
76, 78-80, 84, 85	Other Services	32																	x	x	x			x								x	x	

(Continued on next page. See notes at end of Figure.)

Figure 1.1 (continued)

L Matrices

LAB #	Occupation		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1-5	Eng. and Sci. (1.5%)[a]	1																	x	x				x								x	x	
6-8	Computer Prof. (0.4)	2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
10-13	Health Prof. (2.7)	3																														x		
14	Teachers (4.5)	4																															x	
15	Drafters (0.3)	5	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
9, 16	Other Prof. (6.0)	6																	x	x				x								x	x	
17	Managers (10.6)	7	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
18	Sales Workers (6.6)	8	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
19-24	Clerical (17.8)	9	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
25-28	Constr. Crafts. (3.8)	10																	x	x				x								x	x	
30-32	Metalw. Crafts. (1.3)	11	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
47	Robot Technicians (--)	12				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x	
33	Mechanics (3.9)	13																	x	x				x								x	x	
34-38	Other Craftsmen (4.3)	14																	x	x				x								x	x	
39	Assemblers (1.2)	15				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x	
40	Inspectors (0.8)	16				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x	
41	Packers (0.8)	17				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x	
42	Painters (0.2)	18				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x	
43	Welders (0.7)	19				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x	
44-45	Delivery Workers (2.6)	20																	x	x				x								x	x	
46	Other Operatives (9.4)	21				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x	
48	Janitors (1.5)	22																	x	x				x								x	x	
50	Food Svc. Work. (3.9)	23																	x	x				x								x	x	
49, 51	Other Svc. Work. (6.9)	24																	x	x				x								x	x	
52	Laborers (4.9)	25				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						x	x	
53	Farm Workers (3.2)	26																																

[a] Number in parenthesis shows corresponding percentage of 1978 labor force.

Notes: 1. The first matrix in this figure has 32 rows and 32 columns, corresponding to 32 sectors of the economy. The second matrix has 26 rows and 32 columns, corresponding to 26 occupations and the same 32 sectors as the first matrix. These sectoral and occupational classification schemes are more aggregated than those used in the IEA model. The correspondence is given by the codes in the columns preceding the sector and occupation names in the figure, labelled IEA # and LAB #, respectively. These codes, in turn, are described in Tables 3.1 and 3.7.

2. The letter 'x' indicates an entry that has been explicitly projected for this study. 'x' may represent a zero; e.g., a full column of x's does not necessarily mean that the sector purchases all inputs. 'x' does not necessarily mean that the entry projected for a future year is different from the base year value (although this is typically the case). For example, the column representing Office Equipment is filled with x's because the future input structure of that sector was explicitly examined; however, in the A matrix only a single entry in that column is expected to change significantly from the base year value. Many empty cells contain zeros. For example, the rows for Health Professionals and Teachers each contain only 1 'x' because these workers are virtually all employed by the Health Care and Education sectors, respectively.

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can be seen as reflecting explicit conceptual assumptions about how the economy works, independent of the specific values assigned to different variables and parameters. The structure of the model implicitly determines the range of questions that can be examined, and the dynamic input-output model used in this analysis makes it possible to begin to answer questions--like those analyzed in this study--that could not formerly even be concretely addressed.

The dynamic input-output model is used to project, year by year from 1963 to 2000, the sectoral outputs and investment and labor requirements of the U.S. economy under alternative assumptions about its changing technological structure. Each set of such assumptions constitutes a scenario.

Four different scenarios, S1, S2, S3 and S4, tracing four alternative paths that the U.S. economy might follow between 1980 and 2000, were formulated and computed. These were selected with the view of bracketing among them the upper and the lower limits of the rates at which different sectors of the U.S. economy might be expected to adapt the new technology. The reference scenario, S1, represents the changing input-output structure of the economy, year by year, between 1963 and 1980, but assumes no further automation or any other technological change after 1980: in other words, from 1980 on, robots, numerically controlled machine tools, and automated office equipment, to name a few examples, are used only to the extent that they figured in the average technologies that prevailed in 1980. Final demand, comprising private household consumption, government consumption and net exports, however, is assumed to continue to grow over a projected path through 2000. The computation of this scenario is thus an experiment that allows us to assess future employment and other requirements to satisfy plausible final demand in the absence of technological improvements from 1980 on: it serves as a baseline with which one can compare the other scenarios.

Scenarios S2 and S3 are identical with S1 through 1980 but differ in their technological assumptions for the later years. Both scenarios project an increasing use of computers in all sectors for specific information processing and machine control tasks and their integration. Computerizing each task also involves changes in other inputs, notably labor inputs. While the details are different in each case, Scenario S3 assumes faster technological progress and the more rapid adoption of available technologies than does S2: for example, the availability of more powerful software to dampen the demand for programmers and more rapid elimination of human drafters. Under both scenarios, the demand for computers (measured in constant prices per unit of output) is naturally higher in 2000 than in 1990.

These scenarios also represent the greater use of two other microprocessor-based devices, robots and computer numerically controlled (CNC) machine tools, for a growing range of specific manufacturing operations. Scenario S3 assumes a faster replacement by robots of six categories of production workers in many manufacturing sectors (and associated savings in paint where applicable). It also implies faster substitution than S2 of CNC for conventional machine tools and greater savings per tool in steel scrap leading to corresponding reductions in direct requirements for the metalworking occupations.

All projections assume that computer-based workstations will be replacing conventional office equipment, and that most deliveries after 1985 will be for integrated electronic systems rather than stand-alone devices. The process is accelerated under Scenario S3 where, for example, conventional typewriters are no longer produced after 1985. Corresponding direct impacts on the demand for managerial, sales, and six categories of clerical workers in different sectors of the economy are represented in detail.

Both Scenarios S2 and S3 assume the continuation of recent trends in the input structures of the health care sectors: notably increased use per case of various types of capital equipment for diagnosis and treatment, of drugs and other chemicals, and of plastic disposable items, as well as an expansion of nonphysician medical personnel. These changes proceed more rapidly under Scenario S3 than S2. The health care sectors also continue the automation of office-type operations, with the direct consequences described above. Under Scenario S1, there are no structural changes, in these or in other sectors, after 1980.

Just as computers are increasingly affecting the conduct of professional and leisure activities, the demand for computer-based education, training, and recreation in schools, on the job, and in homes will also increase. In all years through 2000 Scenario S3 assumes far more computer-based courses per student and more teacher training than Scenario S2. It also postulates on-the-job training in more sectors and for a greater number of occupations.

The dynamic input-output model used in this study requires that projections of final demand other than investment--essentially the level and composition of future public and private consumption--be provided from outside the model. For present purposes the same BLS final demand projections (excluding deliveries for investment purposes) were used in Scenarios S1, S2, and S3 so that differences in scenario outcomes have to be attributed exclusively to the different technological assumptions.

We have not yet examined first-hand in detail the implications of technological and demographic change for the future input structures of households, of technological change and alternative government policy for the input structures of the various federal, state and local public administration functions, or of technological change and related shifts in international comparative advantage for the composition of U.S. exports and imports. Under these circumstances we decided that the best starting point would be the BLS final demand projections which, however, have been revised upwards with respect to the use of computers by the military and by households.

Scenario S4 is identical to S3 in all of its assumptions about the technological structure of the economy but the final demand projections incorporated in it are different from those used in the third as well as the first and second Scenarios. The reasons for this are discussed in subsequent sections.

Employment figures shown in this study do not, unless otherwise noted, include either government employees in the armed forces and in public administration positions or household workers, and the value of final demand does not include payments to them.

C. Impacts of Automation on Employment: Principal Findings

This section describes the future demand for labor based on comparisons of alternative projections from Scenarios S1 through S4. The results of some of the computations are shown in the graphs appearing in the Appendix, in each of which changes in one particular variable are plotted under projected alternative scenarios over the period 1963-2000. An examination of graphs #5 and #6 in Section C of the Appendix (p. APP-41), for example, shows that the output of Iron and Ferroalloy Ores Mining (IEA #5)[3] is generally lower and Nonferrous Metal Mining (IEA #6) is generally higher under Scenario S3 than Scenario S1. Despite the clear pattern, however, this is not the case in every year since each curve reflects a distinct pattern of capacity utilization and investment which in turn requires distinct cyclical patterns of production, especially for capital-producing sectors. A preliminary investigation suggests that the cycles of sectoral output and of gross sectoral investment produced by this model for the period 1963-1981 bear a respectable resemblance to those that have been actually experienced. (Actual output and investment figures have in no sense been used to "calibrate" the model.)[4] Nonetheless, careful analysis of the cycles will require a separate study, and here we concentrate instead on the secular trends. Thus, while the tables appearing in this section contain data for individual years, more than a single year is always shown and only relationships of the long-term trends are illustrated.

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[3] IEA #nn refers to sector number nn in the IEA sectoral classification scheme which is given in Table 3.1 of Chapter 3.

The results of this study show that the intensive use of automation will make it possible to achieve over the next 20 years significant economies in labor relative to the production of the same bills of goods with the mix of technologies currently in use. Over 11 million fewer workers are required in 1990, and over 20 million fewer in 2000, under Scenario S3 compared to S1: this represents a saving of 8.5% and 11.7%, respectively, of the reference scenario labor requirements.

The levels and composition of employment in 1978 under Scenarios S1, S2, and S3 are shown in Tables 1.1 and 1.2. BLS estimates for the same year are included for comparison. Since the same BLS sectoral direct labor coefficients were used in the IEA database, it is not surprising that the two sets of estimates for the economy as a whole are within 1% of each other.

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[4] The model systematically fails to replicate the significant downturn of 1982, in large part because of the presumed monotonic growth of final demand from 1980 to 1985. Real GNP in 1982 actually fell.

Table 1.1 Levels of Employment[a] under Scenarios S1, S2, and S3 in 1978, 1990 and 2000 (millions of person-years)

		Scenarios S1, S2, and S3	BLS Estimates[b]
1978	Professionals	13.9	13.3
	Managers	9.5	9.6
	Sales Workers	5.9	5.9
	Clerical Workers	15.9	15.6
	Craftsmen	11.8	12.0
	Operatives	14.0	14.3
	Service Workers	11.1	10.6
	Laborers	4.3	4.5
	Farmers	2.8	2.8
	Total	89.2	88.6

		Scenario S1	Scenario S2	Scenario S3
1990	Professionals	19.8	21.2	20.9
	Managers	14.4	14.4	12.4
	Sales Workers	9.1	8.9	8.2
	Clerical Workers	24.7	21.2	16.7
	Craftsmen	18.0	17.9	17.5
	Operatives	22.0	21.8	21.1
	Service Workers	16.7	16.8	16.8
	Laborers	6.6	6.6	6.4
	Farmers	4.2	4.2	4.2
	Total	135.5	132.9	124.1
2000	Professionals	25.6	28.4	31.1
	Managers	19.0	17.1	11.2
	Sales Workers	12.4	11.8	10.2
	Clerical Workers	32.6	25.0	17.9
	Craftsmen	23.3	22.9	23.4
	Operatives	27.6	26.1	25.8
	Service Workers	22.3	22.4	23.0
	Laborers	8.7	8.6	8.7
	Farmers	5.3	5.3	5.4
	Total	176.8	167.7	156.6

[a] Includes all private sector employment (jobs) plus employment in public education and health. Does not include public administration, armed forces, or household employees.

[b] Calculated from [U.S. Department of Labor, 1981] using the employment definitions of the IEA Model.

Table 1.2 Composition of Employment[a] under Scenarios S1, S2, and S3 in 1978, 1990, and 2000 (percentages)

		Scenarios S1, S2, and S3	BLS Estimates[b]
1978	Professionals	15.6	15.0
	Managers	9.5	10.8
	Sales Workers	6.6	6.7
	Clerical Workers	17.8	17.7
	Craftsmen	13.3	13.6
	Operatives	15.7	16.1
	Service Workers	12.4	12.0
	Laborers	4.9	5.0
	Farmers	3.2	3.2
	Total	100.0	100.0

		Scenario S1	Scenario S2	Scenario S3
1990	Professionals	14.6	16.0	16.8
	Managers	10.6	10.8	10.0
	Sales Workers	6.7	6.7	6.6
	Clerical Workers	18.2	15.9	13.5
	Craftsmen	13.3	13.5	14.1
	Operatives	16.3	16.4	17.0
	Service Workers	12.3	12.6	13.5
	Laborers	4.9	4.9	5.2
	Farmers	3.1	3.1	3.3
	Total	100.0	100.0	100.0
2000	Professionals	14.5%	16.9%	19.8%
	Managers	10.8	10.2	7.2
	Sales Workers	7.0	7.0	6.5
	Clerical Workers	18.4	14.9	11.4
	Craftsmen	13.2	13.7	15.0
	Operatives	15.6	15.6	16.5
	Service Workers	12.6	13.4	14.7
	Laborers	4.9	5.1	5.5
	Farmers	3.0	3.2	3.4
	Total	100.0	100.0	100.0

[a],[b] See Table 1.1.

The subsequent impacts of automation are different for different types of work, and this is apparent even in terms of the 9 broad categories of labor shown in Table 1.1 and 1.2.[5] By 1990 there is a progressive increase in the proportion of professionals and a steep reduction in the number and proportion of clerical workers as we move from Scenario S1 through S2 to S3.

By the year 2000, professionals will account for nearly 20% of all labor requirements under Scenairo S3 compared to 15.6% in 1978, and demand for clerical workers falls to 11.5% from 17.8% in 1978. The demand for managers also slackens noticeably by 2000 under Scenario S3, and in absolute numbers is lower than in 1990 even though in the aggregate 32 million workers have been added to the labor force by the end of the decade according to this scenario.

Section A of the Appendix shows labor requirements at the level of detail of 53 occupations. The increased demand for professionals is seen in that section of the Appendix to be mainly for computer specialists (LAB #6-8)[6] and engineers (LAB #1-4) while the demand for all categories of clerical workers is seen in the graphs to be significantly lower under Scenario S3 than S1.

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[5] Most of the nine aggregate categories are self-explanatory. Craftsmen, operatives, and laborers are sometimes called skilled, semi-skilled, and unskilled blue-collar workers, respectively. The occupational classification scheme is given in Table 3.7 of Chapter 3.

[6] LAB #mm refers to occupation number mm in the IEA occupational classification scheme which is given in Table 3.7 of Chapter 3.

The projected demand for construction craftsmen (LAB #25-28) has a markedly different pattern than that which has been discussed so far: it follows the cycles of the investment demand for structures, and the peaks under Scenario S3 reflect the increased demand for capital. The sharp fall in demand for skilled metal-workers (LAB #30-31) reflects in part the increased use of CNC machine tools.

The impacts of robots on demand for the affected semi-skilled occupations (LAB #39-43, 46)[7] and Laborers (LAB #52) is much more modest. While the reduction in demand for these categories of workers, which is directly attributable to robots, is about 400,000 in 1990 and almost two million in 2000 under Scenario S3, the net demand is about the same as under Scenario S1, apparently due to the offsetting effects of increased production of capital goods.

Sections B and C of the Appendix show labor by sector and output by sector, respectively, and it is of interest to look at the two series of graphs side by side. (All three scenarios assume the same final demand for any given year: personal consumption and residential investment, government purchases, and net exports do not change from one scenario to another. Capital goods which are used in production--investment goods--are not included in final demand.)

One effect of the automation represented in Scenario S3 is reduced requirements for iron and ferroalloys (IEA #5 and

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[7] LAB #46, a residual category of operatives including semi-skilled metal workers, is affected by both CNC machine tools and robots.

36), due in part to the reduced steel scrap attributable to the use of computer numerically controlled machine tools. At the same time, the increased demand for nonferrous metals (IEA #6 and 37) is also notable.

For most sectors these graphs show increases in output accompanied by reductions in employment under Scenario S3 as compared to S1, particularly for many of the metal-working sectors (e.g., IEA #37-44) and Semiconductors (IEA #58). While employment in the computer sector (IEA #50) increases substantially, output grows at a much greater rate. Under the given assumptions--in particular, the same final demand (that does not include investment) for all three scenarios--the increase in the actual output of most service sectors is about the same under alternative scenarios, and the labor savings in the service sectors due to office automation are very substantial, especially for IEA #71-75 and 83-85.

The proportion of employment absorbed in the production of capital goods varies considerably from occupation to occupation. While there are differences over time and across scenarios, it appears that 5-6% of the private economy labor force is employed directly or indirectly in the production of the private economy's capital goods.[8] About 12-15% of craftsmen are involved in the production of capital goods, 9-11% of laborers, and a somewhat smaller percentage of operatives.

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[8] These include capital for public education and health care but exclude other government capital. Also excluded from these figures are residential real estate and other

As could be anticipated, practically no agricultural workers and barely 1% of service workers are involved. While under most scenarios for most years only 2-3% of professionals are so engaged, this rises to slightly more than 4% by 2000 under Scenario S3.

Aggregate gross output is in all years several percent higher under Scenario S3 (and S2) than S1. While most of the increase in output under Scenario S3 relative to S1 is due to the production of intermediate goods (involving an indeterminate amount of "double-counting"), by far the greatest percentage increase (in most years) is in the production of investment goods. In the year 2000, for example, aggregate gross output of these goods is 6.6% higher under Scenario S3 than S1: final demand (comprising personal consumption, government purchases and net exports but not productive investment) is postulated to be the same; output for inter-industry use is 8.8% higher, and investment is 42.3% higher. Figure 1.2 shows annual investment as a percentage of total final demand under the three scenarios, from 1963 to 2000; several BLS estimates and projections are also shown in the figure. The labor savings discussed earlier are, naturally, in part made possible by the substitution of capital for labor.

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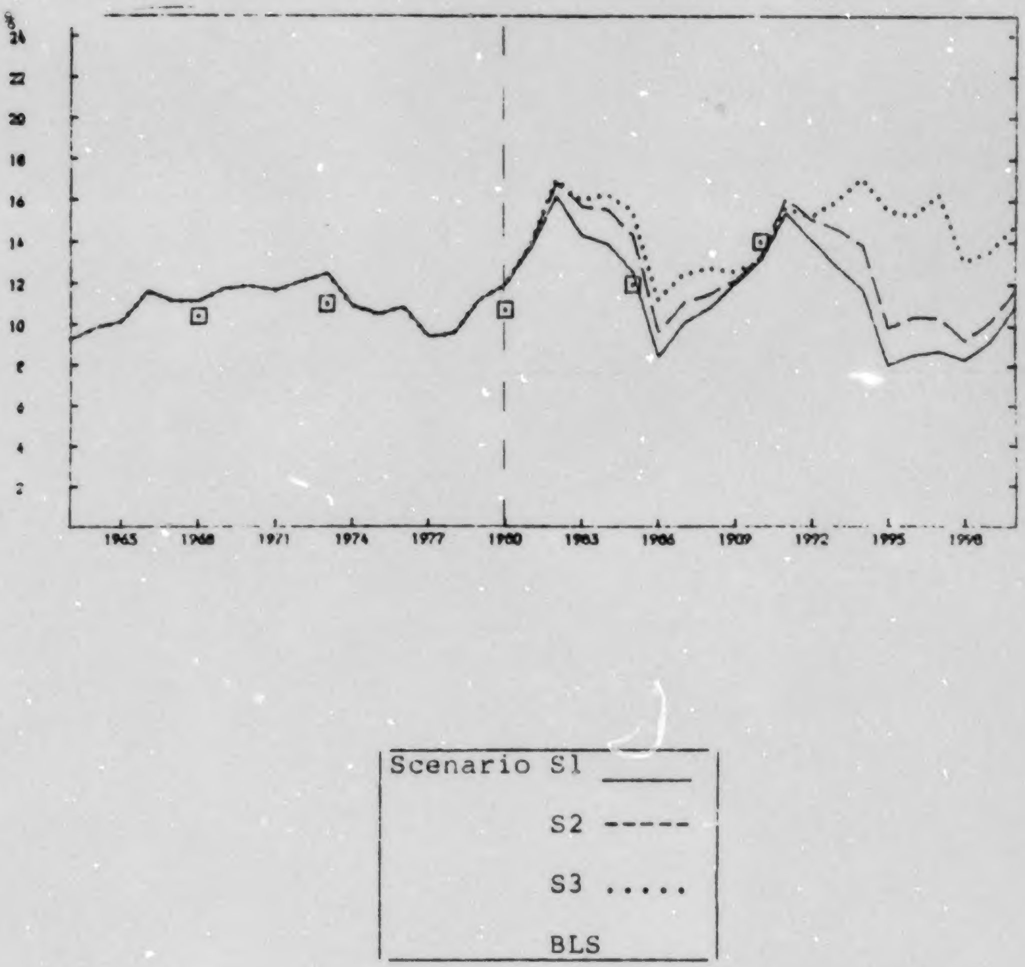
household capital and business inventories which are all accounted for as part of other final demand.

Figure 1.2. Investment as a Percentage of Total Final Deliveries,[a] 1963-2000



[a] Investment is defined as gross private fixed capital formation, including investment for public education and health care. Total final deliveries includes investment.

Source: BLS figures are given for 1968, 1973, 1980, 1985, and 1990 in [U.S. Department of Labor, 1982a, p. 14].

Capital flows under alternative scenarios are summarized in Table 1.3. Investment in this table is cumulated (in constant 1979 prices) over ten-year periods in an attempt to focus on secular changes rather than year-to-year fluctuations. The first three columns of the table show total investment, investment in computers, and investment in robots over three successive decades. During both decades 1981-1990 and 1991-2000, about half the value of the additional investment under Scenario S3 as compared with S1 (or S2) is for computers. Total investment is about 15% higher under Scenario S3 than S1 in the 1980's and 50% higher in the 1990's.

Table 1.3 Total Investment and Investment in Computers and Robots under Scenarios S1, S2 and S3 by Decade

		Gross Investment by Decade (millions of dollars, 1979 prices)			
		Total	Computers	Robots	Computers as proportion of total
1971-1980	Scenarios S1, S2, and S3	$2,304,430	$34,584	$248	1.5%
1981-1990	Scenario S1	3,552,491	68,204	1,870	1.9
	Scenario S2	3,838,773	191,161	5,808	5.0
	Scenario S3	4,069,842	330,228	10,687	8.1
1991-2000	Scenario S1	4,103,334	86,480	2,338	2.1
	Scenario S2	4,686,462	490,766	11,043	10.5
	Scenario S3	6,151,903	1,191,765	29,078	19.4

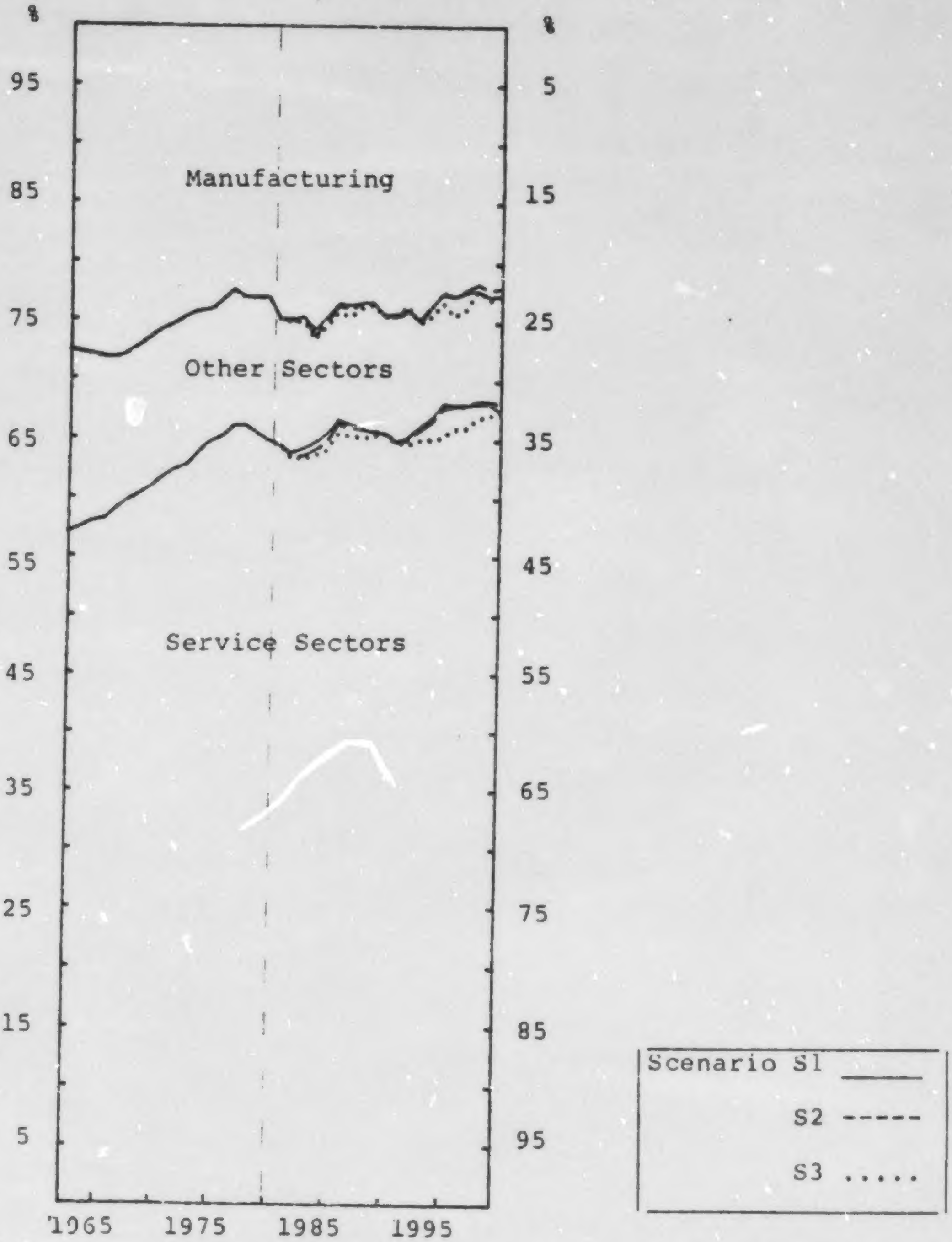
The increasing use of automatic equipment involves shifts not only in the occupational but also in the sectoral distribution of the work force, with the increased production of capital goods slowing the transfer from manufacturing to service sector employment over the next twenty years. This is seen in Figure 1.3, which is a graphic presentation of the percentage of employment in manufacturing, service, and other sectors between 1963 and 2000.

D. Discussion and Implications of the Results

Scenario S3, which is the basis for the following discussion, assumes the accelerated adoption through the year 2000 of computer-based automation into all sectors of the economy, accompanied by a continual increase in the material standard of living. While investment is computed within the IEA model, the other components of final demand (personal) consumption, government purchases, and net exports) are prescribed as explained in Chapter 8. This section introduces an additional scenario, S4, with alternative final demand assumptions.

Table 1.4 shows final demand postulated under Scenario S3 on a per employee and per capita basis for selected years since 1963 and projections for 1990 and 2000. The range of figures shown for future population corresponds to the most recent lowest and highest Bureau of the Census projections. Final demand per capita and its average annual rate of growth are likewise expressed as a range from highest (corresponding to the lowest population projection) to lowest (corresponding

Figure 1.3. Percentage Distribution of Employment among Service, Manufacturing, and Other Sectors, 1963-2000



Note: Manufacturing is defined to include IEA #12-66 and #86. The residual category, Other Sectors, includes Agriculture (IEA #1-4), Mining (IEA #5-10), and Construction (IEA #11). All remaining sectors are included as Services. Public administration, armed forces, and household workers are not included.

Table 1.4. Noninvestment Final Deliveries[a] per Employee-Year and per Capita under Scenario S3 and S4[b] 1963-2000.

	Final Deliveries[a] (millions of dollars) 1979 prices	Final Deliveries[a] per Employee-Year (dollars, 1979 prices)	Population (millions)	Final Deliveries[a] per Capita (dollars, 1979 prices)	Average Annual Rate of Growth in Final Deliveries[a] Per Capita since Last Benchmark Year (%)
Scenario S3					
1963	$1,226,784	$19,189	189.2	$6,484	----
1967	1,442,482	20,725	198.7	7,260	2.87
1972	1,716,593	21,951	209.9	8,178	2.41
1977	1,883,452	21,850	220.2	8,553	0.90
1990	2,902,133	23,404	246-255	11,797-11,381	2.50-2.22
2000	3,855,045	24,680	256-282	15,059-13,670	2.47-1.85
Scenario S4					
1990	2,782,565	24,133	246-255	11,311-10,912	2.2-1.9
2000	3,224,360	25,151	256-282	12,595-11,434	1.1-0.5

[a] Final deliveries includes goods and services purchased from the private economy for personal and public consumption and net exports. They exclude gross private fixed non-residential investment.

[b] See text for description of Scenario S4.

Sources: Final deliveries, see Chapter 8; population, [U.S. Department of Commerce, 1979, 1982b, 1982c].

to the highest population projection). The last column of the table shows the real growth of per capita final demand which is postulated in Scenarios S1, S2, and S3 to increase over the next twenty years at about 2% a year under the high population projections.

The first row of Table 1.5 shows the levels of employment which according to Scenario S3 would be required in order to satisfy this growth in total final deliveries (assumed in this as well as in Scenarios S1 and S2). The first four entries of the third row show data for the same employment concept prepared from government sources for benchmark years between 1963 and 1977, and the match with the IEA results is excellent. For 1990, the projection based on BLS assumptions (which are described in the notes to the table) is presented as a range of low to high. Since no comparable figures have been projected for 2000, we include in the last row of the row of the table civilian labor force projections for the purpose of comparison with the IEA employment projections. The difference between the employment concept of the first three rows and the civilian labor force is that the latter measures persons rather than jobs and includes both the unemployed and those employed in households and public administration. For the years shown between 1963 and 1977, this difference amounts to between 6 1/2 and 10 million.[9]

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[9] Public administration is treated here as a final demand sector, and as such its future input structure is based on BLS projections. In future work, technological changes affecting public administration will be projected in terms of individual technological eoefficients, Preliminary computations suggest that public administration employment would be about 15.6% less in 2000 under the technological assumptions of Scenario S3 than those of S1, compared to a difference of 11.7% between the two scenarios for employment in the private economy.

Table 1.5. U.S. Employment Under Scenarios S3 and S4,[a] 1963-2000, and Other Projections

	1963	1967	1972	1977	1990	2000
IEA Employment[b] Estimates and Projections						
Scenario S3	62.8	69.6	78.2	86.2	124.1	156.6
Scenario S4	62.8	69.6	78.2	86.2	115.3	128.2
Actual and Projected Employment from Other sources[b,c]	62.8	70.9	78.1	87.4	111.0-123.9	not available
Actual and Projected Civilian Labor Force[d]	71.8	77.3	86.5	97.4	123.9-138.3	132.8-157.4

[a] See text for description of Scenario S4.

[b] Includes private sector employment (jobs) plus employment in public education and health. Excludes public administration, armed forces, and household workers.

[c] Entries for 1963-1977 are from [U.S. Department of Commerce, 1981, 1982a]. The ratio of "business" employment (as defined in note 'a') to civilian labor force projected by the BLS for 1990 [U.S. Department of Labor, 1981] was applied to the civilian labor force projections for 1990 which are given in this table. The BLS has not projected figures for 2000. Figures for 1990 and 2000 are reported as a range from low to high.

[d] Entries for 1963-1977 are from [U.S. Department of Labor, 1980]. The range of projections for 1990 and 2000 are based on the most recent population estimates summarized in [U.S. Department of Commerce, 1982b] and rates of participation in the labor force of the portion of the population over age 16 [U.S. Department of Labor, 1982a, Appendix C]. The lowest projection, for example, is calculated from the lowest participation rate and the over-16 portion of the lowest population projection.

Projected labor requirements under Scenario S3 for 1990 fall at the upper limit of the BLS-based projection of 124 million (and the latter assumes an exogenous unemployment rate of about 4%).

Looking further into the future, if the civilian labor force projections reported in the table are accepted,[10] the projected labor requirements of 156.6 million under Scenario S3 for the year 2000 exceed the available labor force (because even a maximum civilian labor force of 157.4 million must allow for public administration, household workers, and some multiple job-holders). Thus the rate of growth in final demand that has been assumed under Scenario S3, based on BLS projections, could not be achieved through only those aspects of technological change that have been represented in this scenario.

The fourth scenario, S4, was formulated to assess what future rates of growth of final demand could actually be attained within the constraints of available labor, according to current labor force projections, and under the technological assumptions of Scenario S3. For Scenario S4 we progressively reduced the level, while maintaining the compositon, of final demand prescribed by Scenario S3 for 1990 and 2000 (and accordingly also for years between 1980 and 1990 and between 1990 and 2000). For each sequence of final deliveries up to the year 2000, the corresponding labor requirements were computed. The procedure was repeated until the computed labor required for 1990 and for 2000 fell within the range of labor force projections reported in Table 1.5. Of course, with additional iterations one could ensure closing in on a prescribed level of final demand that would result in any specific labor force projection (e.g., the midpoints of the ranges shown in Table 1.5). Some results of Scenario S4 are presented in Tables 1.4 and 1.5.

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[10] On the accuracy of such projections, see [Keyfitz, 1981] and [Fullerton, 1982].

When the value (in 1979 prices) of final demand--excluding investment--under Scenario S3 (based on BLS projections) is reduced by 4.4% in 1990 and 16.8% in 2000 (compare Scenarios S3 and S4, Table 1.4), the aggregate employment requirements under Scenario S4 fall within the range of the projected labor force (Table 1.5). Because overall economic activity is lower under Scenario S4 than S3, there will be less investment. For this reason the percentage reduction in the demand for labor as compared to that of Scenario S3 is even greater than that of final demand. For any given year, the occupational composition of employment turns out to be virtually identical under Scenarios S3 and S4, with a lower representation under S4 of those engaged particularly in the production of capital goods; for example, craftsmen represent 14.7% of the employed in 2000 compared to 15.0% under Scenario S3.[11]

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[11] In fact, all three scenarios, S1, S2, and S3, were recomputed with the new final demand projections (S4 is the one of the three corresponding to the technological assumptions of S3). All of the observations made earlier in this chapter comparing the results of Scenario S3 to S2 and S1 hold with the new, as well as the original, final demand projections although the actual figures are of course different.

Under Scenario S4, per capita final deliveries grow at about 2% a year through the 1980's and between 0.5-1.1% through the 1990's.[12] This is an estimate of the extent to which real per capita consumption will be able to increase over the next two decades if the entire projected labor force is employed using the progressively phased-in computer-based technologies. Figure 1.4 summarizes the differences in postulated aggregate final demand and resulting levels of employment between Scenarios S3 and S4.

Based on the findings presented in this report, it is not yet possible to pass a final verdict on the question of technological unemployment by the year 2000. Technological changes taken into account in the four scenarios described in it have been limited to computer-based automation. To arrive at a verdict, it will be necessary to ascertain by means of equally detailed factual inquiry and to incorporate into the technical matrices used in these projections other types of change that are bound to take place, for example in agriculture and in the substitution of materials--like plastics for metals on the one hand and for paper on the other. Moreover, we have explicitly excluded from our scenarios any major

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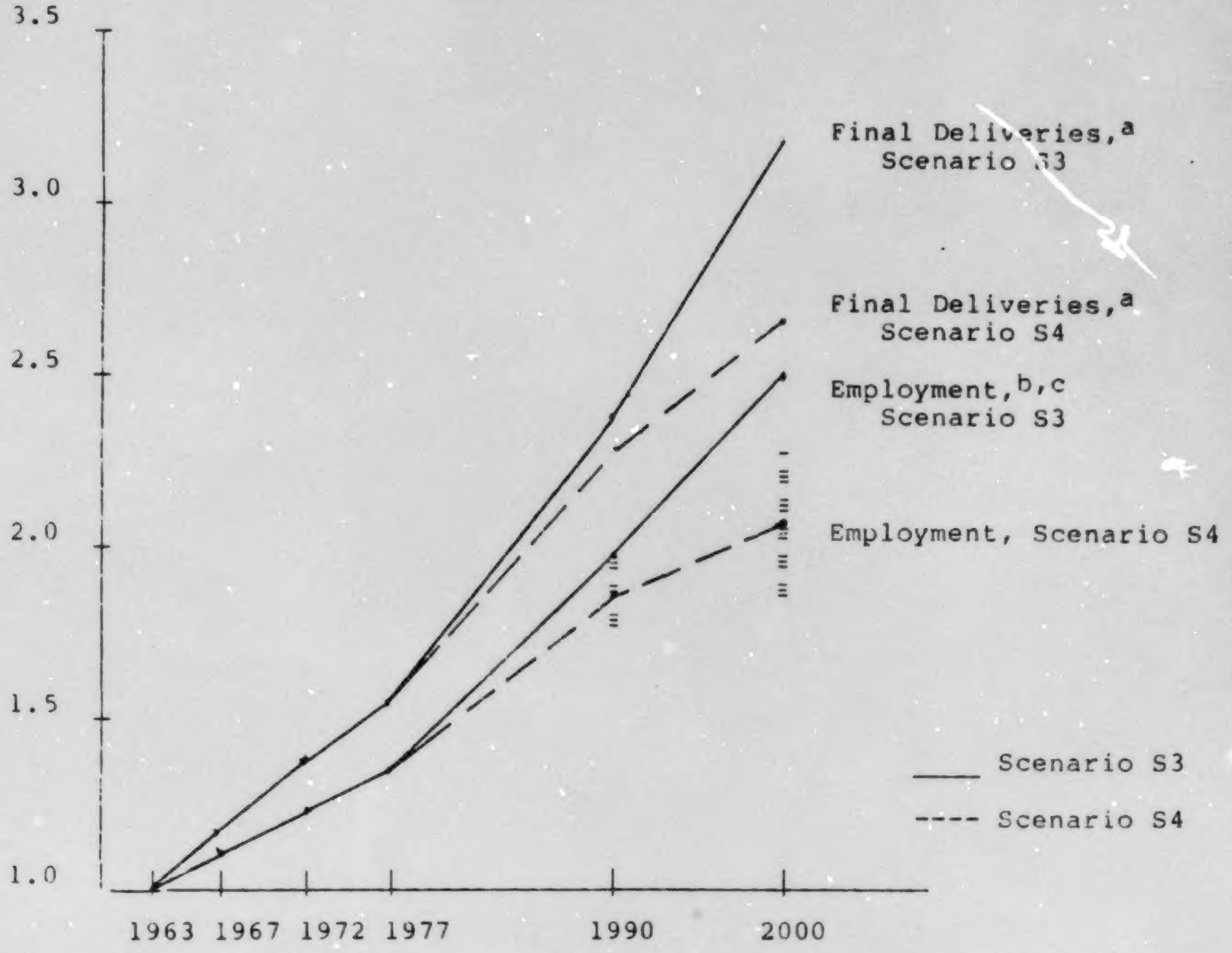
If Figure 1.2, showing investment as a proportion of total final demand, were redrawn for the three new scenarios, all three curves would be almost flat after the late 1990's. The lowering of final demand has this effect since most new capital is introduced when capacity is expanded.

[12] Fixed final deliveries are combined with high-growth and low-growth population projections. Thus the 1.1% rate of growth of per capita final deliveries corresponds to the low population projection, and 0.5% to the high population projection.

Figure 1.4. Growth in Final Deliveries and Employment[b] under Scenarios S3 and S4, 1963-2000

(1963 = 1.0)



[a] See note a, Table 1.4.

[b] See note b, Table 1.5.

[c] Hashed lines (≡) show range of employment projections based on official sources. The range for 2000 assumes the same employment to civilian labor force ratios as given in Table 1.5 for 1990.

Source: Final Deliveries, Table 1.4. Employment, Table 1.5.

break-throughs in computer technology that might affect significant numbers of workers before the year 2000. While it is likely to be at least twenty years before products embodying future break-throughs in areas such as automatic programming, speech recognition, or robot vision are actually adopted on a large scale, some surprises are certainly possible.

The great industrial revolution inaugurated by the introduction of mechanical power continued to transform western economies and society over a period of some two hundred years. The electronic revolution became visible only a few years ago, and by the year 2000 it will be not more advanced than the mechanization of European economies had advanced by, say, the year 1820.

A major consideration in realizing the transition from the old to new technologies will be the availability of workers with the training and skills that match the work that needs to be done. According to Scenario S3, labor requirements to satisfy a continually but moderately increasing standard of living will number 124 million jobs in 1990 with the required occupational composition, reflecting the technologies that will be in place, given in Table 1.1. Let us suppose that there is an adequate total number of individuals to fill these jobs, but that because of very slow change in the orientation of education, training, guidance, and so on, these individuals' skills and occupational expectations will reflect the mix of jobs that corresponded to the technologies that were in place in 1978 (also shown in Table 1.1).

Under these assumptions, 744,0000 managers (0.6% of 124 million), and over five million clerical workers would be potentially unemployed in 1990 while there would be unfilled positions (in the same total amount under the present simple assumptions) in the other aggregate occupational categories. Of course some of those seeking managerial and clerical employment would be able to find jobs of other kinds but with obvious limitations on the degree of job mobility.

The same considerations apply within each broad occupational category. Among professionals, for example, the IEA employment projections for 1990 show a greater proportion of engineers and especially of computer specialists than in 1978. Among skilled workers, the projections include a higher proportion of foremen and production mechanics and a lower proportion of construction and metal-working craftsmen than in 1978.

The crude experiment described above provides of course only a very rough approximation of the ability of the future labor force to fulfill specific job requirements. An adequate evaluation will require comparably detailed analysis of the future structure of households and the job-related attributes of their members. This has not yet been carried out.

Concerted efforts in education and training can facilitate this shift in the occupational composition of the labor force. Scenario S3 requires that the production of electronic educational courseware grow in real terms at over 35% a year in the 1980's and over 10% in the 1990's. (The underlying assumptions about the use of computers in education are discussed at length in Chapter 6.) In the past, higher levels of "conventional" education in the U.S. relative to other countries also played a key role in the successful transformation of our labor force from mainly agricultural workers into a wide range of other occupations. As was the case in the past for conventional education, the growth and quality of computer-based education and its delivery will no doubt become an item of government policy and corporate and trade union strategies.

This study has taken a first systematic albeit partial glance at prospects for employment for almost twenty years into the future, a significant lengthening of the usual time horizon for economic inquiry. With the feasibility and fruitfulness the approach taken in this study now hopefully demonstrated, we need to extend and improve the sector studies on which the scenarios are based and investigate the impacts on the distribution of income implied by the technological assumptions (see [Duchin, 1984]). It will also be necessary, instead of taking final deliveries as given, to formulate and implement a completely closed dynamic input-output model in which consumption and employment are determined simultaneously. These are some of the next steps in our agenda.

In the meantime, the framework developed for this study can profitably be used to investigate numerous critical economic issues which have until now not been subject to systematic inquiry.

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Chapter 2. Dynamic Input-Output Model

A. Introduction

Virtually all of the empirical work to date making use of the input-output (IO) approach has been carried out within the context of the static model in which the levels of all categories of final demand are exogenously fixed.[1] The static IO model, through the matrix of technical coefficients, A (or the so-called Leontief inverse, $(I-A)^{-1}$), represents the interdependency among all the producing sectors of the economy. Any set of outputs computed on the basis of this matrix will be consistent with respect to the levels of activity of all individual sectors at any given time. These properties account for the frequent use of the static IO model.

The objective of the dynamic IO model is to extend these properties to include the determination of the sectoral production and accumulation of capital goods. Each sector's demand for capital goods per unit of its own output is determined by its detailed technical requirements, represented in the capital coefficient matrix B. The model framework imposes intertemporal consistency between the specific capital items produced and delivered in one period and increments of output that in subsequent periods will be available for use. Studying and extending the properties of the dynamic model is at the present time one of the most active areas of theoretical input-output research.

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[1] One noteworthy exception is the World Model [Leontief, Carter, and Petri, 1977], which takes some preliminary steps in "closing" the model for final demand.

The formal dynamic model has never been implemented for two reasons. First, the data requirements are very extensive (as illustrated by Chapters 3 to 5 of this report). But more fundamentally, the implementation of existing formal models would produce implausible results. This chapter describes the characteristics of the dynamic IO model, indicates the nature of the difficulties, and presents the formulation sucessfully implemented for this study.

B. Historical Development

The first dynamic input-output model was formulated by Leontief in 1949 [Leontief, 1953]. He represented investment as the rate of change in required capital stocks, with a vector differential equation of the form

$$x - Ax - B\dot{x} = y \tag{1}$$

where x is the vector of outputs, A is the matrix of input requirements on current account, B is the matrix of capital requirements, and y is the vector of non-investment final demand. Leontief exhibited the form of the solution of Equation (1) in the case where the components of y are exponentials [Leontief, 1953, pp. 59-65], and in [Iverson, 1954] for the first time actual parameters were empirically estimated in numerical solutions of such systems of up to 21 differential equations describing the U.S. economy in terms of 21 inter-related sectors.

Leontief eventually formulated the model in terms of a difference equation with dated technical matrices reflecting structural change in the economy [Leontief, 1970]:

$$x_t - A_t x_t - B_{t+1}(x_{t+1}-x_t) = y_t. \qquad (2)$$

Equation (2) is intended to be solved for the set of vectors of outputs, consistent with the given time sequence of technical matrices and final demand requirements. In theoretical work the system is "closed," i.e., households are treated as a "producing sector" and consumption as its "technologically determined" input vector. In addition, it is assumed that no technical change takes place. Under these circumstances, Equation (2) reduces to:

$$x_t - Ax_t - B(x_{t+1}-x_t) = 0. \qquad (3)$$

A minimal condition for an economically meaningful solution is the existence of a set of nonnegative vectors of output x_t satisfying Equation (3). It is well known that when the model is solved forward in time, a set of nonnegative solutions exists only if the initial conditions lie on the so-called "balanced growth path;" conditions for the existence of a balanced growth path are discussed in [Szyld, 1983]. Actual values for initial conditions will rarely exactly satisfy this constraint.

The fact that negative outputs will typically be generated follows from the implicit requirement in Equations (2) or (3) that the entire physical productive capacity be utilized (i.e., full capacity utilization), which involves both perfect

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[2] The stock is said to be reversible if capital in place but not in use in a particular sector is freely transferable to other uses within the economy. This occurs when elements of $(x_{t+1}-x_t)$ or $\dot{x}$ in Equations (1)-(3) are negative.

foresight of future stock requirements and the "reversibility"[2] of the capital stock. To assure the irreversibility of capital already in place, a "multi-phase process" was suggested [Leontief, 1953] according to which capital stocks are increased only when output grows. In [Uzawa, 1956] this process was represented by replacing the term $B\dot{x}$ in Equation (1) by $B \cdot \max(\dot{x},0)$. Uzawa was able to prove under certain conditions the existence of solutions to this formulation of the dynamic model. The introduction of this nonlinearity amounted to allowing for unused capacity when output is falling.

While this approach appeared promising, Leontief and others [Leontief, 1953; Dorfman, Samuelson and Solow, 1958], were concerned about possible contradictions in switching between this regime when output is falling and the full capacity utilization required when output is rising. This potential problem is not encountered if one (realistically) abandons the requirement of full capacity utilization even when output is growing; but then the model must provide for the determination of a particular, sectoral pattern of capacity utilization. This is the approach taken in the present formulation.

We assume that the effective expansion of a sector's capacity may require several time periods, in which case expansion plans must be formulated and their implementation begun this amount of time in advance. The amount of planned expansion depends upon future sectoral production as anticipated when the plan is formulated. Once in place, the plan is adhered to even if the sector's circumstances change. If adequate capacity is already in place, no expansion plan is implemented. These assumptions are explicitly represented in the following section.

Another difficulty that arises in solving Equations (2) or (3) for x_{t+1} in terms of x_t is the need to invert the capital matrix B. While most theoretical work is carried out at a higher level of abstraction in which it is assumed that the B matrix is invertible, the fact is that the matrix is invariably singular, with rows of zeros corresponding to sectors that do not produce durable (or stockable) goods. It has proved possible (under certain assumptions) to solve the system within the balanced growth framework despite the singularity of the B matrix [Livesey, 1973 and 1976; Luenberger and Arbel, 1977; Meyer, 1982]; but these results have not been used to solve empirical problems in part because of the other difficulties described earlier, such as the assumption of full capacity utilization. Solutions to the model we have devised are obtained at each time step without requiring the inversion of the singular B matrices.

Implicit in the formulation of Equations (2) and (3) is the assumption that the capital goods needed to increase a sector's productive capacity between periods t and t+1 are produced during period t. The algebraic representation of different gestation periods for different capital goods was introduced by [Johansen, 1978] who also demonstrated the existence of a balanced growth path solution for the model he presented, without technological change. The question was further studied by [Åberg and Persson, 1981], and a similar concept had been used by [Belen'kii, Volkonskii, and Pavlov, 1973-5] and [Volkonskii, 1975-6]. Our formulation also allows for different lag structures.

As in the static model, a dual price equation can be written for the dynamic IO model; the price system is not treated in this report.

C. Model Developed for This Study

Our objective was to design a dynamic input-output model to study the effects on labor requirements in the United States of alternative scenarios of technological change between 1963 and 2000. Once a model of the type represented by Equation (2) is solved for the vector of outputs for period t, x(t),[3] the vector of employment requirements by occupation is easily obtained.

In the present formulation, the investment term in Equation (2) is replaced by expressions formulated in accordance with the following considerations:

> Once capacity is in place, it need not be fully utilized and is not reversible.
>
> In each time period, expansion decisions are made for each sector based on recent past growth rates, and capital goods are ordered.
>
> Some capital goods must be delivered several periods before the new facility of which they are part can effectively add to the investing sector's capacity.

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[3] In this section of the chapter, time is represented by the letter t in parentheses rather than as a subscript. We reserve the use of subscripts to denote the specific components (e.g., sectors) of a vector. Equation (2), for example, becomes $x(t)-A(t)x(t)-B(t+1)[x(t+1)-x(t)]=y(t)$.

2.7

> Replacement investment is explicitly represented, separately from expansion.

We introduce two additional (vector) variables:

$c(t)$	output capacity during period t
$o(t)$	increase in productive capacity between periods t-1 and t

and we define $c(t) = c(t-1) + o(t)$. If for sector i, $c_i(t) > x_i(t)$, capacity is under-utilized; if $c_i(t) < x_i(t)$, it is over-utilized.[4]

A sector's future capacity requirements are projected several periods in advance, independent of the capacity in place. For that reason we also introduce the vector $c^*(t)$ of projected capacity requirements for (future) period k and define the increase in capacity in sector i as:

$$o_i(t) = \max[0, c_i^*(t) - c_i(t-1)]$$

Thus if $c_i(t-1) \geq c_i^*(t)$ then $o_i(t) = 0$, no new output capacity is needed, and $c_i(t) = c_i(t-1)$. Otherwise, the change in capacity, o, is the increase needed to achieve the projected capacity requirement, c^*.

The investment term in period k could now be written as $B(t+1)o(t+1)$, implying that investment goods required to increase the capacity in period t+1 are produced and delivered one period earlier. In fact, we recognize that different types of capital goods may have to be delivered two or more periods earlier. We denote by τ_{ij} the lag between the period when a capital item is produced (by sector i) and the period in which it effectively adds to the capacity of sector j and by τ_j the maximum lag for any capital good required by sector j, i.e., $\tau_j = \max_i \tau_{ij}$.

---

[4] Over- and under-utilization are relative to a presumed state of exactly full capacity utilization. Base year rates of capacity utilization are specified in the initial conditions (see Chapter 3), and the concept in the model follows whatever interpretation is used in their derivation.

Planned capacity expansion in sector j will require τ_j periods for its realization and thus will need to be formulated at least τ_j periods in advance. For the present study we make the provisional simplifying assumptions that τ_{ij} and τ_j are the same for all capital-using sectors j. Following [Johansen, 1978, p. 515] we denote as τ_i the lag for capital goods produced by sector i and $\tau = \max \tau_i$.

The investment term now becomes

$$\sum_{\theta=1}^{\tau} B^{\theta}(t)o(t+\theta)$$

where the ij^{th} entry of $B^{\theta}(t)$, $b^{\theta}{}_{ij}(t)$, is the amount of capital produced in period t by sector i to increase the capacity of sector j by one unit in period $t+\theta$.[5] Of course, $b^{\theta}{}_{ij}(t) = 0$ for $\theta > \tau_i$.

In the present formulation future capacity requirements, $c^*(t+\tau)$ planned τ periods in advance, are assumed to be determined by recent past changes in sectoral output. In order to

---

[5] These capital coefficient matrices $B^{\theta}(t)$ are related to $B(t+1)$ of Equation (2) by

$$B(t+1) = \sum_{\theta=1}^{\tau} B^{\theta}(t+\theta-1).$$

prevent excessive expansion plans in time of rapid growth, likely to be followed by a long period of underutilization, a sector-specific maximum admissible annual rate of expansion of capacity, δ, is imposed. (Only the sector's expansion investment and not its output is potentially constrained by δ.) This results in the following expression:

$$c_i^*(t+\tau) = \max \left[1+\delta_i, \frac{x_i(t-1)+x_i(t-2)}{x_i(t-2)+x_i(t-3)} \right]^{\tau+1} x_i(t-1). \qquad (4)$$

We can now write the whole model and solve for $x(t)$ for each period from t_0 through the final period t_T. The initial conditions must specify values for

$c(t_0)$

$x(t)$, $t = t_0-3,\ldots,t_0-1$

Given these initial conditions, we compute c^*, o, and c, in that order, for periods t_0+1 through $t_0+\tau-1$. For each period in turn ($t = t_0,\ldots, t_T$) we first solve for $c^*(t+\tau)$ using (4). Then we compute the future additions to capacity

$$o(t+\tau) = \max\,[0, c^*(t+\tau)-c(t+\tau-1)] \qquad (5)$$

and we update the capacity,

$$c(t+\tau) = c(t+\tau-1) + o(t+\tau). \qquad (6)$$

Replacement investment is represented as

$$R(t)x(t)$$

where the ij^th entry of the replacement matrix $R(t)$ is the amount of capital goods produced by sector i that must be replaced in order to produce a unit of output of sector j during period t. We can now solve for $x(t)$ from

$$[I-A(t)-R(t)]x(t) = \sum_{\theta=1}^{\tau} B^{\theta}(t)o(t+\theta)+y(t). \qquad (7)$$

(Inversion of the B matrices is clearly not at issue in this formulation.) Thus Equation (2) has been replaced by Equations (4-7).

Finally, labor requirements by occupation during period k are obtained as

$$e(t) = L(t)x(t) \qquad (8)$$

where the qj^th element of L(t) is the amount of labor of occupation q required to produce a unit of output of sector j during period t.

D. Data Requirements

Most of the data required to implement this model, for empirical investigation, are presented and documented in the appropriate chapters of this report.

We know of no systematic empirical work on the lag, by item of physical capital, between the time it is delivered and when it becomes productive. In all the computations carried out for this report, we have assumed a maximum lag $\tau=3$ in order to permit a crude distinction among plant, major equipment, and capitalizations that are likely to be put into production shortly after delivery. Table 2.1 shows the lags, τ_i of from 1 to 3 periods assigned to the different capital-producing sectors. They are very rough estimates and in future work should be based on empirical investigation.

The sectoral ceilings on annual anticipated rates of real growth of output $\{\delta_i\}$, which are used in the determination of future capacity (but do not directly constrain the sector's

Table 2.1. Sectoral Lags

Code	Sector	Years
11	Construction	3
12	Ordnance and Accessories	2
36	Primary Iron and Steel Manufacturing	2
37	Primary Nonferrous Metals Manufacturing	2
39	Heating, Plumbing and Structural Metal Products	2
40	Screw Machine Products and Stamping	2
41	Other Fabricated Metal Products	2
42	Engines and Turbines	2
46	Metalworking Machinery and Equipment	2
47	Special Industry Machinery and Equipment	2
48	General Industrial Machinery and Equipment	2
49	Miscellaneous Machinery Except Electrical	2
50	Electronic Computing and Related Equipment	2 (1)[a]
52	Service Industry Machines	2
53	Electric Industrial Equipment and Apparatus	2
60	Miscellaneous Electrical Machinery and Supplies	2
64	Scientific and Controlling Instruments	2
65	Optical, Ophthalmical and Photographic Equipment	2
	All other capital-producing sectors	1

[a] The lag for IEA #50, Electronic Computing and Related Equipment, is 2 from 1963 to 1969 and 1 thereafter.

future growth), are shown in Table 2.2. For most sectors that ceiling is assumed to be 5%, potentially limiting expansion investment so that at full capacity utilization, real output capacity four periods ahead will be no more than 21.6% higher than output in the current period. (The model permits more than "full" utilization of capacity, however.) As shown in the table, twelve sectors were assumed to operate with higher limits on anticipated growth for purposes of capital planning.

Table 2.2. Maximum Annual Anticipated Growth Rates for Projection of Future Capacity Requirements

Code	Sector	Real Rate of Growth
50	Electronic Computing and Related Equipment	20% (15,12)[a]
51	Office Equipment, except IEA #50	15
57	Electron Tubes	10
58	Semiconductors and Related Devices	15
59	Other Electronic Components, nec	15
77	Business Services	10
81	Hospitals	7
82	Health Services, excluding Hospitals	7
83	Educational Services	7
86	Robotics	15
87	Instructional TV	20
88	Computer-based Instruction	20
	All other	5

[a] The maximum rate for IEA #50, Electronic Computing and Related Equipment, is 20% from 1963 to 1969, 15% from 1970 to 1979 and 12% thereafter.

• • •

By decoupling actual output from productive capacity and in addition refining the representatition of investment in several ways, the dynamic input-output model described in this chapter provides a suitable framework for empirical analysis. The Appendix contains the graphic results of the analysis described in this report.

2.13

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Chapter 3. Data, 1963-1980

A. Introduction

The dynamic model which is described in Chapter 2 requires extensive data on production, capital and employment by industry. Most of these data are made available in various publications by the Department of Commerce or the Department of Labor.

The basic sources of information are the IO studies published for 1963, 1967 and 1972 by the BEA, in the Department of Commerce [U.S. Department of Commerce, 1969, 1974a, 1979]. The IO table for each of these three years describes the flows of commodities produced and consumed by each industry and the commodities absorbed by different final uses: private consumption, capital formation, government purchases and foreign trade. The BEA has also produced capital flow tables (CFT's) for 1963, 1967 and 1972 [U.S. Department of Commerce, 1971b, 1975a, 1980] which disaggregate the investment portion of final demand in the corresponding IO table and show the flows of the different fixed capital goods to the industries which use them. The official IO study prepared for 1977 by the BEA is not yet published, but the BLS in the U.S. Department of Labor has made available a preliminary IO table for 1977 [U.S. Department of Labor, 1982b].

Price indexes for IO industries and several series on sectoral capital stocks and flows are produced by the BLS which has also prepared detailed occupation by industry matrices for 1960, 1970, and 1978. Other sources of information which have been used are described in the course of the chapter.

The preparation of the data required reconciling different classifications and conventions among data sources and from one IO study to the next. Some of the changes correspond to an improvement in methodology. Others are explained by actual changes in the economy: technical change, for example, involves the appearance and disappearance of certain commodities and the industries which produce them. When it was possible, we tried to transform the earliest data to conform with the latest conventions. Differences and incompatibilities among data sources are explained mainly by the decentralized approach to the collection of government data.

The IEA model is computed on an annual basis and is used to analyze the effects of technological change in the long-term. Linear extrapolation was used to produce matrices of coefficients for the years between the benchmark years for which full detail is available.

The changes required to make conventions and valuation uniform in the different IO studies are explained in Section B of this chapter. It includes also a presentation of the industrial classification used in the model, the treatment of imports, secondary products, and eating and drinking places, and deflation of the data so that all magnitudes would be expressed in 1979 prices.

Section C is devoted to computations required to obtain the three matrices of coefficients A, B and R. Data for initial conditions and control totals are described in Section D followed by an explanation of the of data describing employment by industry and occupation, in Section E. The description of coefficent matrices for 1978-1980 in Section F ends this chapter.

B. Conventions and Valuation

1. Sectoral Classification Scheme

One of the first steps in preparing the database involved selecting of sectoral and occupational classification schemes and reconciling the existing official data series into these categories. This section describes the sectoral classification scheme used in preparing the A, B, R, and L matrices with particular reference to the BEA IO and capital flow tables used in their preparation.

The capital flow tables which enter into the computation of B and R matrices contain columns showing the detailed commodity composition of gross investment in fixed capital for 77 sectors.

The 1963 and 1967 BEA IO tables consist of 368 sectors while the 1972 BEA IO table and the 1977 BLS IO tables have been further disaggregated to 496 sectors. Several BEA sector codes do not appear at all in our classification. These include so-called Special Industries (Government Industry, Household Industry, Rest of the World Industry, and Inventory Valuation Adjustment) which contain only the value added portion of the corresponding final demand sectors. The "dummy" industries reflect the secondary production of certain goods and vanish when the industry by industry table of transactions is calculated. Noncompetitive imports (explained below) are treated as external to the transaction table and are included in value added.

3.4

The industrial classification of the BEA IO tables is based on the Standard Industry Classification (SIC). The SIC was revised between 1963, 1967 and 1972 (described, respectively, in the SIC manuals of 1957, 1967, and 1972, [U.S. Executive Office of the President, 1957, 1967, 1972]). While the changes between the 1957 and 1967 editions were minimal, substantial changes took place between 1967 and 1972. Most sectors at the level of detail of the IEA classification were unaffected, however, and among those that were affected, we were able to ascertain that the impact was small by comparing BLS sectoral outputs conforming to one SIC classification with BEA sectoral outputs conforming to the other. The discrepancies were significant, however, for three sectors (IEA #4, Agricultural, Forestry, and Fishery Services; IEA #32, Leather Tanning and Finishing; and IEA #79, Automobile Repair Services). In the absence of further information, the BEA representation for each benchmark year was maintained.

A major objective in determining the sector scheme was to segregate those sectors likely to be major actors in the production or adoption of automated equipment, like computers and semiconductors. A detailed representation of the important "service" sectors was desirable because of their large employment and intensive use of computers.

The sectoral classification scheme for the IEA database contains 89 sectors, including three newly emerging ones not yet included in official data series; the classification scheme is shown in Table 3.1. It follows the 2-digit BEA classification

Table 3.1. IEA Sectoral Classification and Corresponding BEA Codes

IEA Code	Description of Sector	BEA Code
1	Livestock and Livestock Products	1
2	Other Agricultural Products	2
3	Forestry and Fishery Products	3
4	Agricultural, Forestry, and Fishery Services	4
5	Iron and Ferroalloy Ores Mining	5
6	Nonferrous Metal Ores Mining	6
7	Coal Mining	7
8	Crude Petroleum and Natural Gas	8
9	Stone and Clay Mining and Quarrying	8
10	Chemical and Fertilizer Mineral Mining	10
11	Construction	11, 12
12	Ordnance and Accessories	13
13	Food and Kindred Products	14
14	Tobacco Manufactures	15
15	Broad and Narrow Fabrics, Yarn and Thread Mills	16
16	Miscellaneous Textile Goods and Floor Coverings	17
17	Apparel	18
18	Miscellaneous Fabricated Textile Products	19
19	Lumber and Wood Products, except Containers	20
20	Wood Containers	21
21	Household Furniture	22
22	Other Furniture and Fixtures	23
23	Paper and Allied Products, except Containers	24
24	Paperboard Containers and Boxes	25
25	Printing and Publishing	26
26	Chemicals and Selected Chemical Products	27
27	Plastics and Synthetic Materials	28
28	Drugs, Cleaning and Toilet Preparations	29
29	Paints and Allied Products	30
30	Petroleum Refining and Allied Industries	31
31	Rubber and Miscellaneous Plastic Products	32
32	Leather Tanning and Finishing	33
33	Footwear and Other Leather Products	34
34	Glass and Glass Products	35
35	Stone and Clay Products	36
36	Primary Iron and Steel Manufacturing	37
37	Primary Nonferrous Metals Manufacturing	38
38	Metal Containers	39
39	Heating, Plumbing and Structural Metal Products	40
40	Screw Machine Products and Stampings	41

(continued on next page)

3.6

41	Other Fabricated Metal Products	42
42	Engines and Turbines	43
43	Farm and Garden Machinery	44
44	Construction and Mining Machinery	45
45	Materials Handling Machinery and Equipment	46
46	Metalworking Machinery and Equipment	47
47	Special Industry Machinery and Equipment	48
48	General Industrial Machinery and Equipment	49
49	Miscellaneous Machinery, Except Electrical	50
50	Electronic Computing and Related Equipment	51.01
51	Office Equipment, Except IEA #50	51 except 51.01
52	Service Industry Machines	52
53	Electric Industrial Equipment and Apparatus	53
54	Household Appliances	54
55	Electric Lighting and Wiring Equipment	55
56	Radio, TV, and Communications Equipment	56
57	Electron Tubes	57.01
58	Semiconductors and Related Devices	57.02
59	Electronic Components, nec.	57.03
60	Miscellaneous Electrical Machinery and Supplies	58
61	Motor Vehicles and Equipment	59
62	Aircraft and Parts	60
63	Other Transportation Equipment	61
64	Scientific and Controlling Instruments	62
65	Optical, Ophthalmical, and Photographic Equipment	63
66	Miscellaneous Manufacturing	64
67	Transportation and Warehousing	65
68	Communications, Except Radio and TV	66
69	Radio and TV Broadcasting	67
70	Electric, Gas, Water and Sanitary Services	68
71	Wholesale Trade	69.01
72	Retail Trade	69.02
73	Finance	70.01-.03
74	Insurance	70.04,.05
75	Real estate and Rental	71
76	Hotels, Personal and Repair Services exc. Auto	72
77	Business Services	73
78	Eating and Drinking Places	74
79	Automobile Repair Services	75
80	Amusements	76
81	Hospitals	77.02
82	Health Services, excluding Hospitals	77.01,.03
83	Educational Services	77.04
84	Nonprofit Organizations	77.05-.09
85	Government Enterprises	78, 79
86	Robotics Manufacturing	______
87	Instructional TV	______
88	Computer-Based Instruction	______
89	Public Education	(final demand column)

with the following exceptions. The BEA sectors for new and maintenance construction were aggregated into a single construction sector; and federal, state, and local government enterprises were likewise combined into one IEA sector. On the other hand, BEA #51, Office, Computing, and Accounting Machines, was split into two sectors with computers separated from other office equipment. BEA #57, Electronic Components and Accessories, was split into the rapidly growing Semiconductors and Related Devices, Electron Tubes, and the remainder. Trade was divided into wholesale and retail, and Finance and Insurance are shown separately. BEA #77 was subdivided into Hospitals, Other Health Services, Educational Services, and Nonprofit Organizations. In our scheme, purchases of residential real estate are taken out of the capital matrices and put into final demand because the demand for this investment is not directly determined by the productive requirements of the economy. Public Education and Health are treated as producing sectors which sell to final demand.

2. Imports

The U.S. IO tables make a distinction between imports which are comparable with domestic production and those which do not have any equivalent produced inside the U.S. The first are called comparable imports and the second, noncomparable.

The treatment of noncomparable imports does not present any particular problem as it is identical in the four IO studies (1963, 1967, 1972 and 1977) where noncomparable imports appear as a row.

The treatment of comparable imports changed between the earlier IO studies (1963 and 1967) and the later ones (1972 and 1977). In the present work we have adopted the conventions used for the 1972 study and modified the 1963 and 1967 tables to match these conventions. After showing the differences in the two treatments of imports, we describe the procedure used to modify the transactions tables, the final demand tables and the capital flow tables for 1963 and 1967.

In the 1972 and 1977 IO tables, the total output of each industry measures domestic production and excludes imports. Consistent with this approach, imports are shown as negative entries in a final demand column. Since their valuation must be comparable with the producers' prices used for the domestic production of the same commodity, comparable imports are measured at domestic port value, which includes the external, usually transoceanic, margin required to bring the commodity to the U.S. border and duty owed on this import. When the transoceanic transportation is provided by a U.S. carrier, the margin is also shown as a positive entry in the cell of the import column related to the transportation industry. By convention, duties are also shown as a positive entry in the cell of the import column corresponding to the trade sector (see Table 3.2).

For the 1963 and 1967 studies the BEA used a "transfer" treatment of comparable imports for industrial use. Like secondary products, imports were transferred to the industry whose output was comparable. Therefore, there is an additional row for imports, besides the one for non-comparable imports, called "transferred imports." The total output shown for an industry equals its domestic output plus the amount of imports of a comparable commodity.

Table 3.2. Cost Structure of Imports

Foreign port value		Domestic port value	Purchasers' value
Water transportation	External or transoceanic margins		
Air transportaion			
Duty			
Insurance			
Rail transportation	Internal margins		
.			
.			
.			
Retail sales tax			

Source: [U.S. Department of Commerce, 1980, p. 22].

Transferred imports are shown at the foreign port value and external margins associated with their shipment are included in the Trade, Transportation and Insurance rows.

Replicating the 1972 treatment of comparable imports for industrial use in the 1963 and 1967 tables requires three steps:

- The domestic port value of transferred imports is determined by adding the external margins related to these shipments to the foreign port value of the imports shown in the table.
- These values are included as negative entries in a new import column in the final demand part of the table.

- In order to avoid double counting of the external margins, the total of each type of external margin is algebraically added to the cells of the new import column corresponding to the "margin industries."

The new representation no longer includes a row for transferred imports.

All imports consumed by final users are allocated directly to final demand in the row containing "directly allocated imports" (both comparable and noncomparable) in the final demand tables and the capital flow tables for 1963 and 1967. These purchases are balanced by a negative entry in the cell of this row corresponding to the column of net exports. In 1972, comparable imports are combined with domestic goods in each final demand column and balanced by a negative entry in the imports column of final demand. To make 1963 and 1967 CFT's comparable with 1972, aggregate comparable imports for final users have to be allocated among the producing sectors.

Fortunately, the publications of the BEA related to the CFT's for 1963 and 1967 [U.S. Department of Commerce, 1971, 1975a] provide information on imports of capital goods. We assumed that all imports for 1963 and 1967 were imports of comparable capital goods and distributed all imported commodities like their domestic equivalents, as the BEA did for 1972. The total imports of each capital good was added as a negative entry to the corresponding cell of the new imports column in the final demand tables for 1963 and 1967.

No attempt was made to reallocate the imports absorbed by personal consumption,[1] which in any case accounted for only about 2% of personal consumption expeditures. No adjustments to the final demand tables other than those described above were required for present purposes.

3. Secondary Products

Even individual establishments frequently produce two or more commodities: the main product is called primary and any others are considered secondary. For many purposes it is desirable to represent secondary products as being produced by the industries to which they are primary; the resulting industries are defined in terms of a single output, facilitating a technological interpretation for the input coefficients. The BEA changed its treatment of secondary products in the 1972 study.

The method used by the BEA in its 1972 study makes an explicit distinction between industry and commodity and involves the USE table which describes the utilization of different commodities by the different industries, and the MAKE table which describes the production of different commodities by the different industries. By convention an industry is given the same name as its primary product.

We combined the USE and MAKE tables in order to make an industry by industry representation, a choice influenced by availability of employment data on an industry, not commodity or process, basis. A row of the resulting matrix shows the utilization of the mix of commodities produced in the given year by the corresponding industry.

---

[1] Full import vectors for the 1963 and 1967 IO tables are now being developed in the course of other Institute research.

To reorganize the IO data in this way, we used the pattern of distribution of different commodities as shown in the USE table. The information in the MAKE table makes it possible to attribute a fraction of the total output of each commodity to the industries which actually produce it. This transformation assumes that, when a commodity is produced by several industries, it is as if all users buy it in the same proportions from the different producers. These proportions are equal to the share of the different industries in the total production of that commodity.

The algebra of the transformation of a commodity by industry to an industry by industry classification is the following:

$$T = WU,$$

where T is the industry by industry table, W is the coefficient matrix obtained after dividing each cell of the MAKE table by the corresponding column total, and U is the USE table. The same transformation must also be applied to the final demand columns and the CFT's.

The method described above was used for 1972 and 1977, years for which USE and MAKE tables are available. For 1963 and 1967 we reconstructed USE and MAKE tables from published data.

In the studies for 1963 and 1967, the BEA used a "transfer" approach, in which a secondary product is sold by the producing industry to the industry for which it is the primary product. Since this sale is fictitious, the method overestimates intermediate inputs for the "buying" industry.

Data available (from the BEA on magnetic tape) for these two years show separately the direct allocation, i.e., the real transaction, and the transfer. A table containing only direct allocations is conceptually identical to a USE table. A table containing only transfers is comparable to a MAKE table with empty cells on the main diagonal.

To complete the MAKE table we required, for the main diagonal, the production of each industry's primary commodity. By definition this amount is equal to the total production of that commodity less the amount produced as secondary product by other industries. The total output of a commodity is represented by the corresponding row total of the USE table. The amount produced as secondary product by other industries is the column total of the transfer table. The cells on the main diagonal of the MAKE table were filled using this information, and then the procedure described earlier for (1972 and 1977) was applied to the 1963 and 1967 IO tables.

Scrap and used and secondhand goods are treated as secondary products. Since this category of goods is considered a single commodity, every user of scrap appears to use a small amount of the production of every industry producing scrap and used and secondhand goods.

The number of secondary products identified as such in the later studies is larger than in the earlier ones, and we have not attempted to resolve the discrepancy. In all other respects, the methodology described above allows us to prepare the input-output tables for 1963, 1967, 1972, and 1977 such that each treats secondary products in the same way.

4. Eating and Drinking Places

In this section we describe the methods used to resolve the inconsistencies created by the lack of an Eating and Drinking Places (E&D) sector in the 1963 and 1967 I-O tables. Prior to 1972 E&D (IEA #78, BEA #74) was included in Retail Trade as a margin sector. This meant that its input structure did not include the purchase of food, beverages and other materials but only the margin costs of providing a service (electricity, containers, etc.). Since 1972 it is treated as a separate, productive sector that transforms the product it sells.

We have created an E&D row and column and removed E&D activities from other sectors for 1963 and 1967, using the following information:

- structure of E&D (column and row) in the BEA 1972 table
- gross output of E&D in 1963 and 1967 (provided by BLS)
- industrial compostion of Personal Consumption Expenditure by PCE category, in producers' and purchasers' prices ("bridge tables") [U.S. Department of Commerce, 1971a, 1974b].

The BEA publishes tables of purchases of meals and beverages for personal consumption, shown for 1967 in Table 3.3. These purchases correspond exactly to personal consumption of E&D, which accounts for over three-fourths of E&D output and provides the basis for our E&D column.

Table 3.3 Purchases of Meals and Beverages Out of Personal Consumption Expenditures in 1967 (millions of 1967 dollars)

Producing Sector (BEA Codes)		Producer's Prices	Transportation	Trade Margin	Purchaser's Prices
1	Livestock and Livestock Products	$ 126	$ 9	$ 204	$ 339
2	Other Agricultural Products	361	52	628	1,042
3	Forestry and Fishery Products	271	53	392	716
14	Food and Kindred Products	8,379	186	13,230	21,795
27	Chemicals and Selected Chemical Products	8	0	7	15
69	Wholesale Trade	541	0	0	541
80	Noncomparable Imports	6	1	12	19
	Total	9,692	302	14,473	24,467

Source: [U.S. Department of Commerce, 1974b].

While Wholesale Trade and Retail Trade are combined in Table 3.3, they need to be distinguished for the E&D column since the first is a cost (i.e., an input) and the second is now a part of the product.

The 1967 IO study provides the trade margins for the aggregate deliveries of the sectors identified in Table 3.3: these margins are shown in Table 3.4. In constructing the E&D column we assume that Wholesale Trade is the same proportion of direct allocation as it is for the total sales of the corresponding sector.

Table 3.4 Distribution of Retail and Wholesale Trade Among Sectors Supplying Purchased Meals and Beverages to Personal Consumption in 1967 (millions of 1967 dollars)

Producing Sector (BEA Code)		Direct Allocation	Retail Trade	Wholesale Trade	Wholesale Trade/Direct Allocation
1	Livestock and Livestock Products	18,112	4,264	1,581	.087
2	Other Agricultural Products	37,562	24,927	6,136	.163
3	Factory and Fishery Products	4,486	4,002	960	.214
14	Food and Kindred Products	609,746	252,071	79,858	.131
27	Chemicals and Selected Chemical Products	5,046	2,135	321	.064

Source: [U.S. Department of Commerce, tape, 1974a].

Finally, total E&D output is available for 1963 and 1967 [U.S. Department of Labor, 1982a]. For 1967 it was $34,312 million or $75,138 million in 1979 dollars (the value unit for the IEA database).

The E&D column can now be constructed. First, the total value of E&D output at purchaser's price is distributed between the value of the product and transportation and trade margins according to the porportions given in the last row of Table 3.3; this is shown explicitly in the last row of Table 3.5. Then the product is distributed among the seven producing sectors in the same proportions as in the first column of Table 3.3: this is shown in the first column of Table 3.5. The wholesale component of the trade margin is estimated by applying the ratios in the last column of Table 3.4 to the direct allocation in the first column of Table 3.5. This produces an estimate of the retail trade margin as the difference between the total trade margin and the total wholesale margin. The retail trade portion is then multiplied by the input coefficient vector of the retail trade sector, and these flows are treated as additional inputs to E&D. The prices are now inflated to 1979 prices and easily assembled into a column of input coefficients.

Table 3.5 Input Structure of Eating and Drinking Places
(millions of 1967 dollars)

Producing Sector (BEA Codes)		Producer's Prices	Transportation Margin	Retail Trade Margin	Wholesale Trade Margin	Purchaser's Prices
1	Livestock and Livestock Products	177			15	
2	Other Agricultural Products	506			83	
3	Forestry and Fishery Products	380			81	
14	Food and Kindred Products	11,750			1,539	
27	Chemicals and Selected Chemical Products	11			1	
69	Wholesale Trade	759			-	
80	Noncomparable Imports	8			-	
	Total	13,592	423	(18,578)	(1,719)	34,312
				20,297		

The 1963 and 1967 E&D coefficient columns constructed in this way were roughly comparable with the one for 1972, except for Crude Petroleum and Natural Gas, IEA #8. This sector provided virtually no input into E&D in 1972 while our construction resulted in a substantial flow for 1963 and 1967 which we set to zero in the absence of a substantive explanation for a large input in the earlier years.

The E&D sector is known to sell about three-fourths of its output to personal consumption. In the absence of additional information, the E&D rows were constructed by allocating the remaining 25% of its output according to the 1972 distribution.

The input structures of other sectors were adjusted to be consistent with this treatment of E&D. No longer do they purchase food from the food stuff-producing sectors and a margin from Retail Trade; this now comes as a package from E&D. Reductions in the affected inputs were made for all purchasing sectors using the same information needed to construct the E&D column.

5. Deflation

In order to represent all values in base year 1979 prices, the deflators prepared by the Office of Economic Growth of the BLS were selected for the following reasons:

> They are deflators of gross sectoral output (rather than value added deflators used in the National Accounts).
>
> They are industry deflators and take into account the product mix of the individual sector and its change over time.
>
> The classification follows closely the BEA IO classification and is available at a high level of disaggregation (155 sectors).

To take full advantage of the detail of the BLS deflators, the final demand, transactions, and capital flow tables were deflated at this level and then aggregated to the IEA 85-sector classification: this step involved the reconciliation of classification schemes. 1979 was chosen as the base year because it was the latest year for which full price data were available when this work was done.

While the BLS series shows almost no price change in Electronic Computing and Related Equipment (IEA #50) over the period 1963-1977, the business and technical literature suggests that the price has in fact been declining at least 10% a year on the average. A similar observation holds for Semiconductors and Related Devices (IEA #58). The BLS deflators were replaced by a 10% a year decline in price for both sectors. While other official deflators may also overestimate price increases because of a conservative assessment of changes in the nature or quality of the output, these are the most important cases for the purposes of this study.

A separate issue arises in the case of the so-called service sectors, where the official total output deflators are in many cases based (inappropriately) on the changing cost of labor inputs. For this study, we have defined "physical" measures of output for private and public educaton, IEA #83 and #89, whose output we represent in millions of student-years, and for Instructional Television (ITV) and Computer-Based Instruction (CBI), IEA #87 and #88, whose output is measured in terms of hours of electronic courseware.

C. Coefficient Matrices, 1963-1977

1. Interindustry Transactions (A Matrix)

After the data had been standardized, deflated, and aggregated to the IEA 85-sector classification as described above, the parts of the IO tables for 1963, 1967, 1972, and 1977 containing the interindustry flows were organized into an

A matrix of technical coefficients for each of these benchmark years. Each technical coefficient is obtained by dividing an entry of the flow table by the corresponding row total. Thus the element in the i^{th} row and j^{th} column of an A matrix is computed as the total amount of output of sector i consumed by sector j, divided by the total output of sector j in the corresponding time period (measured in 1979 prices or in physical units). For years between benchmark years, each coefficient was linearly interpolated.

2. Replacement of Fixed Non-Residential Capital (R Matrix)

In the dynamic IEA model replacement of existing capital and investment for expansion are treated separately. While a sector's planned increases in the productive capacity provided by its stock of physical capital are determined by comparing projected future capacity requirements with capacity already in place, investment to replace fixed assets is assumed to depend upon the current level of sectoral activity.[2] In either case the *composition* of investment will be dictated essentially by technical requirements. This section describes the methodology for allocating past gross investment between replacement and expansion and for computing the coefficients of the replacement matrix, R. The i^{th} element of the j^{th} row of R specifies the amount of output of sector i purchased by sector j to maintain its productive capacity during a particular time period.

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[2] Investment also takes place for technological modernization in the absence of growth: capital may replace noncapital inputs or obsolescent capital. This issue arises, for example, in the case of robots (Chapter 4).

In the absence of systematic, direct observation of the fixed capital in each industry, official government series on capital stocks use a "perpetual inventory" approach to record the accumulation of new capital and the discard of existing assets using an initial observation of stocks, subsequent data on gross investment, and assumptions about the lifetimes of different capital goods. Within this framework, replacement investment is that which compensates for the retirement of fixed assets. For those sectors whose capital stock is contracting, scrapping of fixed assets exceeds replacement, and we have attempted to represent the amount of replacement that actually takes place.

The BLS publishes annual data on capital stock, investment, and retirement of equipment and structures by industry, computed in a perpetual inventory framework, for the years from 1947 to 1974 [U.S. Department of Labor, 1979].[3] These data do not specify the physical composition of the stocks or flows. We have relied for this information on the BEA capital flow tables for 1963, 1967, and 1972, which describe the deliveries in a given year of over 600 capital goods to each sector of the economy in the 2-digit BEA classification, i.e., 77 capital-using sectors. These tables were standardized, deflated, and aggregated as described earlier. Column totals measure each industry's gross investment, and column proportions show the corresponding composition. Sectoral gross investment as reported by the BLS and BEA do not always rely on the same sources and are not identical. We adopted the BEA series to maintain as much consistency as possible with the rest of the input-output studies.

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[3] The Bureau of Industrial Economies in the U.S. Department of Commerce recently made available a new set of data on capital stocks by industry which has not been incorporated in the present study.

The replacement flow matrices are computed in the following way. The BLS ratio of discards to gross investment is multiplied by the BEA estimate of gross investment, resulting in the level of replacement investment of the given sector in a particular year. The composition of this replacement investment is assumed to be the same as that of the corresponding sector's gross investment as reported in the CFT. Each sector's replacement of equipment and of structures (the latter assumed to be produced exclusively by the construction sector) is computed separately and takes into account the relatively slower rate of replacement of structures. Finally, the technical coefficients of the R matrix are computed by dividing these flows of replacement capital by the total output of the using sector. This representation of replacement reflects the assumption that a sector will replace only the portion of its stock required for current production.

Since the CFT's exist only for 1963, 1967, and 1972, R matrices can be directly computed only for these years. For the years in between, each coefficient was linearly interpolated. The 1972 R matrix was repeated for each year through 1977 with a few exceptions which are described in the appropriate portions of Part III of this report.

3. Expansion of Fixed Nonresidential Capital (B Matrix)

The j^{th} column of the expansion matrix, B, measures the stock of each type of capital good required to increase the capacity of sector j by one unit. The stock of each kind of capital good is measured in the same unit as the output of the sector that produces it. In the present case this unit is a 1979 dollar's worth.

Especially in capital-intensive sectors, very detailed plans are on the drawing-boards of engineers years before a capital project is actually realized, and investigators at the Battelle Memorial Institute have made use of this type of information to produce expansion matrices like those required for our data base [Fisher and Chilton, 1971]. While it proved impractical to use the Battelle matrices due to the impossibility of assuring consistency between the conventions used in constructing these tables and those employed in assembling the rest of our database, we expect to return to this so-called ex ante method for constructing the B matrix in future work. The present study relied on the accounting information in the government data series.

While data are available on annual sectoral output and net investment (the latter series resulting from the data work described in the preceding section of this chapter), it was not possible to deduce a technologically meaningful relationship between the two without taking into account other factors, like sectoral rates of capacity utilization.

Instead of deducing stock requirement from the capital flow data, we chose instead to use the sectoral capital to output ratio to govern the total amount of capital required for a unit expansion in capacity. It is true that capital to output ratios measure the average capital requirement, rather than incorporating the most advanced techniques that are typically used by new facilities and that are conceptually required by our representation. Until better data are available, we can observe that using the average in place of the "best technology" ratio does not introduce a systematic over- or under-statement of net investment, since the average and therefore the best technology ratio does not appear to be monotonic but depends upon specific technological events (see, for example [Duchin, 1983]).

The B matrices for 1963, 1967, and 1972 were prepared in the following way. Sectoral capital stock estimates for the benchmark years, available in [U.S. Department of Labor, 1979] in 1972 prices, were inflated to 1979 prices using the NIPA price index for non-residential fixed investment [U.S. Department of Commerce, 1982]. These measures of the total capital stock held by each sector were divided by corresponding sectoral outputs, resulting in sectoral capital to output ratios. Since the industrial classification of the capital stock series is less detailed than the IEA classification, a single capital to output ratio was in several instances used for more than one sector.[4] (While the specification of the model calls full capacity output in the denominator of the capital to output ratios, we did not make this adjustment for the present study.)

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[4] The industrial classification of the capital stock series follows the two digit IO classification with two exceptions: the four agricultural sectors (BEA #1 - 4) are aggregated together, as are New and Maintenance Construction (BEA #11 and 12).

The vectors of capital to ouput ratios for a given year, measuring total stocks required to produce a unit of output, are by definition the column totals of the corresponding B matrix. Expansion capital was assumed to have the same product composition as gross investment, so the column totals were distributed over capital-producing sectors in the same proportions as in the columns of the Capital Flow tables for the corresponding years. The coefficients of the B matrices were computed in this way, and then interpolated between benchmark years and projected to 1977 in the same way as that described in the last section for the R matrix.

The B matrix is subsequently decomposed into B^{θ}, $\theta = 1,2,3$, according to the lag between the delivery of a capital item and its effective use in production. This subject is discussed in Chapter 2.

D. Initial Conditions and Control Totals

The IEA model requires estimates of sectoral capacity for the initial year and projections of future capacity (based on estimated sectoral expansion plans) for the next five years (as discussed in Chapter 2). In addition, during the development of the model it was necessary to prepare "control totals" for sectoral outputs and investment to check the values produced by the model. This section describes the preparation of data for initial conditions and controls.

1. Sectoral Rates of Capacity Utilization

When a sector's capital stock is being fully utilized, its productive capacity is equal to its output. Given its output and an estimated rate of capacity utilization, the capacity can be computed. Sectoral capacities for 1963 were derived in this fashion from utilization rates published by BEA [U.S. Department of Commerce, 1975b], using a classification scheme very close to ours.[5] When the BEA sectors were more aggregated than the IEA classification, we used the same rate for each part of the larger sector. For those sectors not explicitly reported (exclusively service sectors), we followed the source document in assuming 100% capacity utilization. The ratios used in the model are given in Table 3.6.

2. Sectoral Outputs

Output vectors for benchmark years were produced by standardizing, deflating, and aggregating the IO transaction flow tables (see Section B) and these vectors were linearly interpolated for the years in between. These data were used both to estimate capacity in 1964-1968 and as controls to check the performance of the model and signal potential problems.

3. Fixed Nonresidential Investment

Controls were also prepared for fixed nonresidential replacement and expansion investment. These numbers were

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[4] This source defines these rates as "actual utilization rates as a percent of preferred utilization rates." See also Chapter 2, footnote 4.

computed from a recent BEA publication [U.S. Dept. of Commerce, 1982] which provides annual gross fixed nonresidential investment through 1979 in current and constant 1972 dollars, separately for equipment and structures, as well as discards of fixed capital.

Separate deflators for equipment and structures were computed using the data in current dollars to convert the series to 1979 prices.

E. Employment Data

The final requirement of the IEA model was for data on the use of labor by occupation per unit of each sector's output. The principal sources of information are the occupation by industry matrices prepared by the BLS for 1960, 1970, and 1978 from [U.S. Department of Labor, 1973, 1981].

The occupation by industry matrix for 1960 is based on the 1960 Census of Population and includes 186 occupations and 157 industries. The matrix for 1970 is based on the 1970 Census, while that for 1978 is an update incorporating data from various surveys. These last two matrices include 425 occupations and 260 industries. Neither the sectoral nor the occupational classification scheme is incompatible with that of the 1960 matrix.

For this study we used a 53-occupation classification scheme, given in Table 3.7. At this level of aggregation, the BLS employment categories for 1960 and later years were comparable with only a few discrepancies that were resolved using further detail from the 1960 Census of Population.

Table 3.6. Capacity Utilization by Sector in 1963

Sector		Capacity[a] Utilization
5,6	Metal Mining	.81
7	Coal Mining	.82
8	Crude Petroleum and Natural Gas	.91
9,10	Stone and Earth Minerals Mining	.88
11	Construction	.89
12	Ordnance and Accessories	.68
13	Food and Kindred Products	.90
14	Tobacco Manufacturers	.96
15,16	Textiles	.84
17,18	Apparel and Miscellaneous Fabricated Textiles	.94
19,20	Lumber and Wood Products	.90
21,22	Furniture and Fixtures	.87
23,24	Paper and Allied Products	.85
25	Printing and Publishing	.87
26-29	Chemicals, Plastics, Drugs and Paints	.79
30	Petroleum Refining and Allied Industries	.93
31	Rubber and Miscellaneous Plastics Products	.78
32,33	Leather Products	.93
34,35	Glass, Stone and Clay Products	.92
36	Primary Iron and Steel Manufacturing	.80
37	Primary Nonferrous Metals Manufacturing	.80
38-41	Fabricated Metals	.83
42-52	Machinery, except Electrical	.72
53-60	Electrical Machinery	.82
61	Motor Vehicles and Equipment	.85
62	Aircraft and Parts	.68
64,65	Instruments	.83
66	Miscellaneous Manufacturing	.85
67	Transportation and Warehousing	.85
70	Electric, Gas, Water and Sanitary Services	.94
71,72	Trade	.94
76	Hotel, Personal and Repair Services, except Auto	.66
86	Robotics	--
	All Other Sectors	1.00

[a] Defined as proportion of "preferred" rates of utilization as in the source.

Source: [U.S. Department of Commerce, 1975b].

To ensure compatibility with the IEA sectoral classification, we attempted to match sector definitions of the three BLS employment matrices to the IEA 85-sector classification at the level of the component SIC codes. When the BLS sector included several IEA sectors, the corresponding employment levels were decomposed according to sectoral outputs assuming the same occupational structure for each sub-sector. Once the classificational discrepancies were reconciled, the employment data took the form of three flow matrices of 53 occupations by 85 sectors for 1960, 1970, and 1978.[6] The row totals of these matrices show private sector employment by occupation, and the column totals correspond to private sector employment by sector of the economy.

The BEA has published aggregate employment by IO sector, using the definitions and conventions of their IO studies for 1967 and 1972 [U.S. Department of Commerce, 1978 and 1981b]. Discrepancies for some sectors between these data and the column totals of the BLS matrices were resolved by using the BEA totals which were augmented by estimates of the number of self-employed by sector, from other sources. BLS matrices were used to determine the occupational composition of employment for each sector. BEA sectoral employment is consistent with the NIPA employment series which, while more aggregated in their sectoral classification, were available for 1963 and

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[6] In fact, a fourth matrix was prepared based on BLS projections for 1990. It is used in this study only for purposes of comparison with IEA projections (in Table 1.1).

Table 3.7 IEA Occupational Classification and Corresponding BLS Codes

IEA Code	Description of Occupation	BLS Code[a]
Professionals		
1	Electrical Engineers	10020200
2	Industrial Engineers	10020250
3	Mechanical Engineersl	10020300
4	Other Engineers	1002 (except 10020200, 10020250, 10020300)
5	Natural Scientists	1004, 1006
6	Computer Programmers	10160050
7	Computer Systems Analysts	10160100
8	Other Computer Specialists	10160150
9	Personnel and Labor Relations Workers	10240650
10	Physicians and Surgeons	10100300
11	Registered Nurses	10100400
12	Other Medical Professionals	1010 (except 10100300, 10100400)
13	Health Technologists, Technicians	1012000
14	Teachers	10200000
15	Drafters	10080150
16	Other Professional, Technical	1014, 1018, 1022, 1024 (except 10240650)
Managers		1008(except 10080150)
17	Managers, Officials, Proprietors	20000000
Sales Workers		
18	Sales Workers	30000000
Clerical Workers		
19	Stenographers, Typists, Secretaries	40020000
20	Office Machine Operators	40040000
21	Bank Tellers	40060050
22	Telephone Operators	40061550
23	Cashiers	40060200
24	Other Clerical	4006(except 40060050, 40061550, 40060200)
Craftsmen		
25	Carpenters	50020050
26	Electricians	50020350
27	Plumbers and Pipefitters	50020800
28	Other Construction Craft Workers	5002(except 50020050, 50020350, 50020800)
29	Foreman, nec	50040000
30	Machinists	50060300
31	Tool and Die Makers	50060750
32	Other Metal Working Craft Workers	5006(except 50060300, 50060750)

[a] Unpublished BLS classification scheme accompanying [U.S. Department of Labor, 1981].

(continued on next page)

Table 3.7 (continued)

IEA Code	Description of Occupation	BLS Code
Craftsmen (continued)		
33	Mechanics, Repairers	50080000
34	Printing Trade Craft Workers	50100000
35	Transportation, Public Utilities Crafts, Other Craft Workers	50120000
36	Bakers	50140500
37	Crane, Derrick and Hoist Operators	50140200
38	Other Craft Workers	5014 (except 50140050, 50140200)
Operatives		
39	Assemblers	61080100
40	Checkers, Examiners, Inspectors	61060050
41	Packers and Wrappers	61060200
42	Painters	61081050
43	Welders and Flame Cutters	61020500
44	Delivery and Route Workers	62000200
45	Truck Drivers	62000550
46	Other Operatives	6000 (except 61080100, 61060050, 61060200 61081050, 6102 62000200, 62000550)
47	Robot Technicians[b]	--------
Service Workers		
48	Janitors and Sextons	70020150
49	Protective Service Workers	70100000
50	Food Service Workers	70040050, 70040150, 70040250, 70040300
51	Other Service workers	7000 (except 70120000 70020150, 70100000, 70040050, 70040150, 70040250, 70040300)
Laborers		
52	Laborers	8000
Farmers and Farm Workers		
53	Farmers and Farm Workers	9000

[b] In aggregate occupational classification schemes Robot Technicians, IEA #47, are included as Craftsmen.

1977 as well as 1967 and 1972 [U.S. Department of Commerce, 1981a, 1982]. The NIPA data for 1963 and 1972 were disaggregated to 85 sectors using proportions from the 1967 and 1972 BEA employment studies, respectively, when necessary.

The three matrices of occupational proportions (for 1960, 1970, and 1978) were interpolated linearly to produce four matrices for the benchmark years (19[illegible]3, 1967, 1972 and 1977). The four corresponding vectors of total employment by sector were divided, element by element, by total sectoral output (in 1979 prices) in the given year, resulting in sectoral labor/output ratios. Finally these ratios were distributed among occupations according to the matrices of occupational proportions. The final outcome was a set of four matrices for the years 1963, 1967, 1972 and 1977 of labor/output ratios by occupation and by sector.

F. Coefficient Matrices, 1978-1980

Each scenario for which data have been developed in Part IV of this report specifies A, R, B, and L coefficient matrices for 1990 and for 2000. The most recent government IO data are for 1977, and these were in most cases repeated for 1978, 1979 and 1980 with exceptions for newly emerging sectors. The sectors producing electronic educational courseware (IEA #87 and 88) appear in 1980, and the robotics sector (IEA #86) begins production in 1977. Annual matrices are produced by interpolation for 1981-89 and 1991-99.

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Chapter 4. The Automation of Production Operations

A. Introduction

This chapter documents the procedures employed in estimating the changes in capital, intermediate input, and labor requirements that describe the adoption of specific computer-based technologies. While production processes will undergo other changes as well, the widespread use of computers in the office and factory is expected to have major consequences for the level, occupational composition and skill content of future employment. The magnitude of these changes is suggested by General Motor's prediction that "by 1987, 90 percent of all new capital investments will be in computer-controlled machines" [Levitan and Johnson, 1982, p. 12] and by the fact that a Japanese designed plant is already in operation in the U.S. whose automated processes have reduced the number of workers required to produce a given output of machine tools from 500 to 100 [Japan Economic Journal, 1983, p.11].

The impacts of computers are not limited to the production of goods. The application of computers to office work will vastly reduce the need for human labor in performing repetitive tasks such as filing, bookkeeping and typing. These labor savings are of particular significance for the industries employing white-collar labor most intensively, notably banking, insurance, legal services and government. According to projections made by the International Data Corporation [1981a, pp. 4-5], the number of desktop and small business computers in use will increase from 823,000 in 1980 to 5.4 million in 1985, and these figures understate the pace of computerization in the office since they do not reflect advances in hardware and software capabilities.

The increased use of computer-based automation is represented in the database of the dynamic input-output model by changes in the input requirements (or technical coefficients) of the sectors which produce and use the new equipment. Each column of coefficients in the A matrix represents a given sector's inputs on current account per unit of output. The corresponding column in the B matrix represents the sector's capital requirements for a unit expansion of capacity, while a column of the R matrix represents capital replacement requirements per unit of output. Finally, a column of the L matrix represents a sector's labor requirements by occupation per unit of output.

Our focus in this chapter is organized around two facets of the computerization of production processes. (Office automation is addressed in Chapter 5.) First, quantitative sectoral estimates are made of the increasing use of computers (for all purposes) and the associated requirements for Computer Programmers, Computer System Analysts, Other Computer Specialists, and Drafters; these estimates are described in Section B. Second, we represent the increasing use of two specific microprocessor-based machines, robots and computer numerically controlled (CNC) machine tools. The use of robots is projected to conserve paint, while the substitution of CNC for conventional tools will increase the use of metalworking machinery and reduce steel scrap. The use of robots requires a new occupation, Robot Technicians, and displaces workers in six production occupations, while the use of CNC tools reduces the labor requirements of Machinists, Tool and Die Makers, and Other Operatives (semi-skilled metalworking operatives). The procedures used to represent these impacts of robots and CNC tools are described in sections C and D, respectively.

The projections made for this study reflect technologies that are currently known. As Carter [1970, p. 88] has noted, "most major changes in technology of production or product design can be anticipated by industry specialists five or more years before they are put into actual use." We do not project anticipated future breakthroughs nor the commercial use of technologies which have not yet been effectively utilized, but we do assume the incremental improvement of currently available technologies. For example, our estimates take into account the substitution of CNC for conventional machines, computer links between individual CNC machines (Direct Numerical Control, or DNC), and increasing use of machining centers (in which one CNC machine performs several machining operations) but not the future use of Flexible Manufacturing Systems (FMS), in which automatic material handling systems are linked to computer-based machines (including robots) to form an essentially unmanned production process.

Differences among the technologies (computers, robotics, and CNC tools) and among the types of inputs (capital, intermediate input, and labor) made it impractical to use a single general methodology for the projections. In order to represent the use of computers, the increase in each sector's capital coefficient (the computers required to increase capacity by one unit) was based on the increase in the average computer coefficient (computer stock per unit of output), for which data were developed for 1977, 1990 and 2000. Similarly, average capital coefficients for the use of robots were estimated for each robot using industry. Based on the literature about investment in robots, we assumed that the robot requirements per unit of new capacity (the capital coefficients) would reach a peak in 1985 at a value equal to that of the 1990 average robot requirements (the average capital coefficients) for each sector. The 1977 Metalworking Machinery capital coefficients are projected from the estimated share of CNC tools in the value of the machine tool stock required for new capacity in 1990 and 2000.

The projections of the inter-industry and labor coefficients are based on the future use of these three kinds of equipment. Intermediate inputs are adjusted by identifying the portion of the material input (e.g., paint) that will be affected, estimating the change in this affected portion, and adjusting the coefficients accordingly. Labor coefficients for the computer occupations were projected on the basis of the labor required per computer and on projections of the computers used per unit of output. Labor coefficients for various production occupations are adjusted on the basis of

1) the stocks of robots held in each sector and the labor displacement rate per robot, and 2) the CNC share of machine tools in use and the ratio of CNC to conventional labor requirements per unit of output.

Technical coefficients for the A, L, B, and R matrices were projected for alternative scenarios, corresponding to low (Scenario S2) and high (Scenario S3) rates of diffusion of the computer-based technologies. These two scenarios are intended to specify a realistic range for future developments.

B. Electronic Computing Equipment

1. The Computer Sector

Information processing in the office, machine control in the factory, and the integration of office and factory will become increasingly dependent upon a hierarchy of computers over the next two decades. According to a recent report [General Motors, 1982, p. 3], computer-based equipment on the factory floor will be "linked together in a plant's computer communications network that will not only monitor how the equipment is functioning, but will schedule the plant for the most efficient operation."

These computers will range from the desktop variety, which costs less than $10,000, to large mainframe computers that carry a price tag in the $12 million range. In the IEA industry classification, this equipment is produced by IEA #50 and corresponds to the Standard Industrial Classification (SIC) code #3573. This sector does not include microprocessors which provide the basic functions of a computer (input/output, memory, and processing) on a single semiconductor chip. Also excluded from this sector (IEA #50) are special purpose microprocessor-based machines, such as word processors (produced by Office Equipment, IEA #51) and CNC controls for machine tools (produced by Electric Industrial Equipment and Apparatus, IEA #53).

The following section describes the procedures used to estimate future changes in the production of computers. Section 3 describes the projections of the capital coefficients governing the increased use of computers and corresponding changes in labor coefficients to the year 2000.

2. The Production of Computers

The production of computers and semiconductors has undergone dramatic changes since the 1960's. As the composition of computer output has shifted away from mainframes to smaller, standardized computers, the industry has substituted mass production for batch techniques, a trend that has led to a rapid decline in unit costs. In the case of semiconductors, the 1970's saw labor-intensive operations move abroad and an increasing mechanization of the remaining stages of production (wafer fabrication). According to one report, the average selling price of an integrated circuit fell from $4.20 in 1967 to 63 cents in 1975 (1972 prices) [U.S. Department of Commerce, 1979, p. 50].

The intermediate input and labor coefficient columns of the Computer (IEA #50) and Semiconductor (IEA #58) sectors used in this study reflect these structural changes. In the aggregate, the 1972 intermediate input requirements per unit of output of the Computer sector were 48% of their 1967 value (in 1979 prices). By 1977 these requirements in these sectors again fell by about 50%. The decline in labor requirements was even more dramatic, 56% and 68% respectively. The magnitude of the declines in intermediate input and labor coefficients in the Semiconductor sector were similar.

Although we focused our effort on the use of computers, we felt that it was necessary to provide provisional estimates of future reductions in intermediate input and labor requirements for sectors IEA #50 and IEA #58. Since the trends cited above can be expected to continue in the future, these coefficients were reduced under all scenarios by 30% in 1990, and another 30% in 2000.

3. The Use of Electronic Computing Equipment: 1977, 1990 and 2000 Computer Capital Coefficients

The procedures described in Chapter 3 produced a matrix of capital coefficients (B matrix) for each year of the 1963-72 period. Neither the statistical series underlying these matrices nor direct information on the investment in computers required by each sector to accommodate an expansion of capacity was available for years after 1972. Instead, we derived our estimates of the future increase in incremental computer capital coefficients from the increase in the average coefficients, defined as the stock of computers held by each sector per unit of output.

The 1977 capital coefficients appearing in row #50 were derived by applying to the 1972 coefficients the rate of increase between 1972 and 1977 in the average coefficients, or

$$b_{50j}^{77} = \frac{\bar{b}_{50j}^{77}}{\bar{b}_{50j}^{72}} \cdot b_{50j}^{72} \qquad (1)$$

where $\bar{b}$ designates an average capital coefficient. Average coefficients were then estimated for future years, and the incremental capital coefficents for 1990 and 2000 were computed by the equation

$$b_{50j}^{t} = b_{50j}^{77} + \alpha(\bar{b}_{50j}^{t} - \bar{b}_{50j}^{77}) \qquad (2)$$

where the increase in the capital coefficients, representing the newest technology, is α times as great as the increase in the average coefficients. These procedures are described in detail below.

The estimates of average computer coefficients for 1972, 1977, 1990 and 2000 were developed in four steps. First the aggregate stock of computers in 1972 and 1977 was calculated. The gross stock of Office, Computing and Accounting Machinery for these years, published by the Bureau of Economic Analysis [U.S. Department of Commerce, 1982, p. 173], was adjusted to 1) eliminate the office equipment share of this machinery (15%), 2) eliminate trade and transportation margins (10%) in order to value the stock in producer prices, and 3) deflate from 1972 to 1979 prices (a 10% annual decrease in price was assumed). These adjustments produced computer stocks of $10 billion for 1972 and $17.5 billion for 1977.

The second step was to distribute these stocks among using industries. As the basis for this distribution we used the proportion of total computer personnel employed in each sector, since professional computer specialists have until recently been required to operate computers. According to the International Data Corporation [1981a], only 0.6% of the value of computers in use in 1977 were desktops, the category of computers not generally requiring specialized skills for operation.

In the third step we projected the aggregate stock of computers that would be required to produce a 1977 level of total gross output in 1990 and 2000. The growth in the aggregate computer stock coefficient was calculated from the real growth in the gross stock of computers [U.S. Department of Commerce, 1982] and in total gross private sector output [U.S. Department of Labor, 1982] between 1972 and 1979. Between 1972 and 1977, the average annual rate of increase was 8.6%. This average rate rose to 8.9% between 1976 and 1979 and 11.3% for 1978-79. We assumed an average annual rate of 10% between 1977 and 1990 for Scenario S2 and 15% for Scenario S3.

As the stock grows and computers are used in the bulk of the operations that can be computerized, the rate of increase in the computer coefficient can be expectd to decline. For both scenarios, we assumed that the average annual rate of growth between 1990 and 2000 will be half that of the 1977-90 period (5% and 7.5%, respectively).

In the fourth step, the increases in the aggregate stock of computers between 1977 and 1990 and between 1990 and 2000 were distributed among industries on the basis of their projected information processing and machine control requirements. As the operation of computers becomes more accessible to managers, secretaries, engineers and production workers, requirements for specialized computer personnel will diminish, and there may be significant changes in the relative use of computers by sector. We used two methods to distribute the 1990 and 2000 computer stocks among using industries. Most of the increase (90%) after 1977 was assumed to be for information processing tasks and was allocated among industries based on their relative information processing requirements, as measured by their share of total white-collar workers in 1977. The remainder of the increase (10%) was assumed to be associated with machine control requirements in goods producing industries and was distributed among industries on the basis of the relative number of machine tools that were held in 1977.

The projections required partitioning the increase in capital stocks between the base year (1977) and 1990 and 2000 into the portion used for information processing (IP) and the portion required for machine control (MC) in goods production. Each portion was then separately distributed among sectors. The future average computer capital coefficient ($\bar{b}_{ij}{}^{t}$) was defined as the sum of three components,

$$\bar{b}_{50j}^{t} = \bar{b}_{50j}^{77} + \bar{b}_{50j}^{t(IP)} + \bar{b}_{50j}^{t(MC)} . \qquad (3)$$

The average capital coefficients, estimated in this fashion for 1990 and 2000, were used in Equation (2) to compute the capital coefficients.

In order to fix a value for α (the ratio of incremental to average computer requirements) we compared the computer requirements for a given output vector based on the capital coefficients developed with the procedures described in Chapter 3 with the requirements based on the average coefficients just described. The former were naturally systematically larger than the latter; their ratio for the economy as a whole, 2.25, was assigned to α.

The results of Equations (1) and (2) can be briefly summarized. In 1977, the industries with the largest computer requirements per unit of output were those producing Electrical and Electronic Equipment (IEA #51-60), Instruments (IEA #64, 65), Ordnance and Aircraft (IEA #12, 62), Financial Services (Banking and Insurance, IEA #73, 74), and Educational Services (IEA #83, 89). Industries with relatively low requirements for computers per unit of output in 1977 included Agriculture (IEA #1, 2), Mining (IEA #7, 10) and several Service (IEA #75, 79) industries, as well as Construction (IEA #11), Food (IEA #13) and Lumber (IEA #19): the common characteristic of these latter sectors is the predominance of small establishments. Most of the computer equipment in 1977 consisted of mainframes which were expensive and designed for large tasks, and these industries consequently used relatively little of this equipment.

The industries with the largest increases in computer coefficients subsequent to 1977 are those with large information processing requirements whose operations are conducted in small establishments: Retail Trade (IEA #72), Real Estate (IEA #75), Hotels (IEA #76), Amusements (IEA #80) and Educational Services (IEA #83, 89). The major part of the computer equipment that will be used by these industries will be desktop computers and electronic cash registers.

Table 4.1 shows fifteen industries that were projected to have large computer capital coefficients in 1990 and 2000. Using the Aircraft industry (IEA #62) as an example, $45,000 in computers was required to increase capacity by $1 million in 1977; by 2000 this requirement will reach $191,000 under Scenario S3. The nine manufacturing industries shown in this table are among the earliest candidates for computer-based flexible manufacturing systems, e.g., Screw Machine Products (IEA #40), Metalworking Machinery (IEA #46), and Aircraft (IEA #62). The seven service sectors have significant information processing requirements and include Retail Trade (IEA #72) Finance (IEA #73), Insurance (IEA #74) and Business Services (IEA #77).

Labor Coefficients

Many occupations have already been directly affected by the increasing use of computers in the production of goods and services. In this section we describe the method used to estimate future changes in the labor coefficients for three occupations (Programmers, LAB #6, Systems Analysts, LAB #7

Table 4.1. Capital Coefficients for Computers in the Sectors with the Largest Coefficients in 1990 and 2000 (dollars per dollar increase in capacity, 1979 prices)

Code	Sector	1977	Scenario S2		Scenario S3	
			1990	2000	1990	2000
40	Screw Machine Products and Stampings	.006	.045	.079	.088	.192
46	Metalworking Machinery and Equipment	.011	.077	.136	.150	.326
47	Special Industry Machinery and Equipment	.009	.055	.096	.105	.227
49	Miscellaneous Machinery, except Electrical	.012	.103	.184	.203	.446
55	Electric Industrial Equipment and Apparatus	.005	.045	.080	.088	.193
57	Electron Tubes	.029	.076	.118	.128	.252
62	Aircraft and Parts	.045	.075	.103	.109	.191
64	Scientific and Controlling Instruments	.013	.050	.084	.092	.192
68	Communications, except Radio and TV	.018	.064	.105	.115	.239
72	Retail Trade	.006	.070	.127	.141	.311
73	Finance	.081	.162	.234	.250	.464
74	Insurance	.084	.141	.191	.203	.354
77	Business Services	.037	.088	.132	.143	.277
82	Health Services, excluding Hospitals	.008	.048	.084	.092	.198
84	Nonprofit Organizations	.010	.104	.189	.210	.463

and Other Computer Specialists, LAB #8) which depend wholly upon the use of computers, and one occupation (Drafters, LAB #15) which is being eliminated by computers.

The labor coefficients for the three computer occupations in computer using sectors[1] were projected to 1990 and 2000 on the basis of 1) estimates of the number of computer workers required per unit of computer stock, and 2) the projected 1990 and 2000 computer requirments per unit of output. As stated in a recent BLS study, "Employment of computer workers . . . reflects an industry's capital expenditures for technology as employers install computers to increase efficiency and productivity, whether or not their output is expanding" [U.S. Department of Labor, 1981, p. 7].

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[1] The coefficients for the computer occupations in the Computer sector (IEA #50) were reduced by the procedure described earlier in part 2 of this section.

Given the number of workers required per unit of computer stock (e_{qj}/k_{50j}), the new labor coefficient (l_{qj}) will vary with the amount of computers that are used per unit of sector j's output ($b_{50,j}$):

$$l_{qj} = e_{qj}/x_j = (e_{qj}/k_{50j})(\bar{b}_{50j}) \qquad (4)$$

The computer personnel requirements per unit of computer stock were computed for each sector for 1977. Recent developments in both software and hardware suggest that in the future these labor to computer stock ratios will fall. According to a recent BLS study [U.S. Department of Labor 1981, p. 20],

> One trend in software technology has been the incorporation of systems programming functions into computer hardware. If the trend continues over the next decade, it may curb the demand for some systems programmers. . . . Packaged programs are another software option available to computer users. These programs, which are being developed for an ever increasing number of applications, simplify programming operations, reduce programmer skill requirments, and may require fewer programmers at a computer site. . . . These packaged programs also will permit programming to be done by noncomputer personnel in many cases.

Table 4.2 shows aggregate ratios of computer workers to computer stock for three computer occupations for the census years 1972 and 1977, and these ratios show substantial declines for all three computer occupations.

We assume that these ratios continue to fall until 1990. Such a trend is supported by a recent study by the International Data Corporation which found that among 350 computer users over the 1981-83 period, the staff-related share of the budget has steadily fallen while the computer room equipment portion has risen [Zientara, 1983, p.1]. Under Scenario S2, advances in software and reductions in maintenance requirements were assumed to reduce employment per computer to 67% of the 1977 ratio for each sector and each computer occupation by 1990. Under Scenario S3, these advances were assumed to be more rapid, and the ratios were reduced to 33% of the 1977 figures. The ratios remain unchanged between 1990 and 2000 under both scenarios.

Table 4.2. Aggregate Labor-to-Computer Stock Ratios for Three Computer Occupations (workers per million dollars, 1979 prices)

Occupation	1972	1977
Programmers (LAB #6)	15.0	11.0
Systems Analysts (LAB #7)	11.6	9.0
Other Computer Personnel (LAB #8)	2.5	2.1

The labor coefficients for 1990 and 2000 were calculated by multiplying these ratios by the average computer capital coefficients ($\overline{b}_{50j}$). The industries with the largest 1990 and 2000 labor coefficients for Computer Programmers are presented in Table 4.3. The coefficients increase over time since increasing average computer requirements per unit of output more than offset falling labor requirements per unit of computer stock.

In contrast to the future prospects of these three computer occupations, Drafters (LAB #15) are among those occupations

Table 4.3. Labor Coefficients for Computer Programmers in the Sectors with the Largest Future Coefficients in 1990 and 2000 (workers per million dollars of output, 1979 prices)

Code	Sector	1977	Scenario S2		Scenario S3	
			1990	2000	1990	2000
46	Metalworking Machinery and Equipment	.060	.241	.417	.230	.492
49	Miscellaneous Machinery, except Electrical	.055	.290	.523	.290	.639
51	Office Equipment, Except IEA #50	.235	.296	.415	.222	.400
57	Electron Tubes	.166	.247	.351	.188	.344
72	Retail Trade	.027	.190	.342	.189	.417
73	Finance	.151	.333	.536	.293	.597
74	Insurance	.174	.286	.436	.236	.462
77	Business Services	.435	.905	1.470	.804	1.650
81	Hospitals	.044	.199	.337	.185	.393
83	Educational Services	.243	1.430	2.280	1.240	2.510
84	Nonprofit Organizations	.061	.283	.503	.278	.609
85	Government Enterprises	.021	.239	.436	.242	.538
89	Public Education	.243	1.430	2.280	1.240	2.510

which will be adversely affected by the increasing use of computers. In 1978 there were 296,000 Drafters, 90% of whom worked in private industry preparing "detailed drawings based on rough sketches, specifications and calculations made by scientists, engineers, architects, and designers. They also calculate the strength, quality, and cost of materials" [U.S. Department of Labor, 1980, p. 315]. There is ample evidence in the business and technical literature that computer-aided design (CAD) greatly facilitates the performance of these tasks. According to Allan, [1982, p. 95], "with CAD a designer can now define a part's shape, analyze stresses applied to it and automatically produce engineering drawings for that design, all from a computer-based graphics terminal." Once drawings are automatically produced, they can be stored easily retrieved for modification.

CAD will affect Drafters in two ways. First, the time consuming menial tasks will be performed by the computer, eliminating all but the most skilled "senior drafters" who are qualified to translate preliminary drawings by engineers and architects into design layouts for the computer. For example, "Normally an architect and one or more draftsmen would spend 3 days modifying the design, changing the specifications and redrawing the building. This time an architect made the changes on a video screen in a matter of hours and new drawings were in the mail the same day" [Miller, 1982, p. C1].

The second effect of CAD on drafters is the improvement in the productivity of the relatively skilled drafters who are not replaced. According to a Society of Manufacturing Engineers report [Kidd and Burnett, 1981, p. 1], "It has been proven conclusively many times that CAD can improve the productivity of the designer/draftsman by factors of between 2:1 and 5:1 depending upon the applications."

The equation used to estimate the 1990 and 2000 labor coefficients for Drafters incorporates these two effects:

$$l_{qj}^{t} = \alpha(1-\beta)(1-\gamma)l_{qj}^{77} + (1-\alpha)l_{qj}^{77} \quad . \qquad (5)$$

where l_{qj}^{t} is the labor requirement for Drafters per unit of output of sector j at time t; l_{qj}^{77} is the labor coefficient for the base year (1977); α is the share of Drafters affected by CAD; β is the share of affected Drafters who are replaced by

CAD; and γ measures the increase in drafter productivity attributable to CAD. This first term of the equation is added to the remaining (unaffected) portion to produce the new coefficient.

Already by 1985, computer-based graphics terminals are expected to number at least 75,000 [Allan, 1982, p. 96]. According to Dan Luria of the United Auto Workers, by 1990 there will be no Drafters employed in the Auto industry. We assumed that under Scenario S2 50% of all Drafters will be affected by CAD by 1990, while 90% are affected under Scenario S3. In the year 2000, the share of Drafters affected rises to 90% and 100%, respectively. By 1990, 20% of the affected Drafters are assumed to be replaced under Scenario S2 and 80% under S3. In 2000, these figures are 50% and 100%, respectively. Finally, we assumed that CAD improves the productivity of Drafters by a factor of three. Since one Drafter using CAD can replace the work of three Drafters using conventional methods, labor requirements decline to 33% of their previous level, a reduction (γ) of 67%. These assumptions are summarized in Table 4.4.

As the last row of the table indicates, under Scenario S2 the Drafter labor coefficient declines to 63% of the base year coefficient in 1990, and falls to 25% of the base year coefficient in 2000. With a larger share of Drafters affected and replaced under Scenarios S3, the coefficient is only 16% of the base year coefficient in 1990. Under this scenario, Drafters cease to exist as an occupation by the year 2000.

Table 4.4. Impact of Computer-Aided Design on Labor Coefficients for Drafters in 1990 and 2000

	Scenario S2		Scenario S3	
	1990	2000	1990	2000
Proportion of Drafters (LAB #15) Affected by CAD $(\alpha)^a$	.50	.90	.90	1.00
Proportion of Affected Drafters Replaced by CAD $(\beta)^a$	.20	.50	.80	1.00
Reduction in Drafter Requirements Attributable to CAD $(\gamma)^a$	.67	.67	.67	.67
Labor Coefficients for Drafters as Proportion of 1977 Coefficient	.63	.25	.16	.00

[a] These parameters are used in Equation (5).

C. Robotics

1. Overview of the Technology

Within the universe of production machinery, industrial robots are unique in their programmability, flexibility of movement, and range of functions that allow them to perform tasks that could previously be performed only by human labor. This is implicit in the Robot Institute of America's definition of a robot as a "reprogrammable, multi-functional manipulator designed to move material parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks" [Sockolow, 1981, p. 40].

While industrial robots vary widely in function and complexity, all include three basic components: the manipulator includes the robot frame and mechanical parts; the controller determines the sequence of motions, and in the more complex, intelligent robots these motions are programmed with numerically-controlled (NC) tapes or microprocessors; the motor drives the robot and can be one of three types, pneumatic, hydraulic or electric. Electric motors are most advantageous for small robots requiring precise, clean operations and low maintenance.

Robots are currently used in processes as diverse as forging, welding, assembling, painting and machine tool loading. According to Ayres and Miller [1983, p. 25], the tasks that the current generation of robots can accomplish include loading and unloading CNC machine tools, die casting machines, hammer forging machines, etc.; spray painting on an assembly line; cutting cloth with a laser; making molds; manipulating tools such as welding guns and drills; and assembling simple mechanical and electrical parts. The following examples of robot installations indicate the variety of functions robots are beginning to perform and the kinds of labor impacts that have been experienced.

> Honeywell introduced four robots "to perform most of the functions handled by the machine operator" and claims a 10% increase in production and a 50% decline in labor costs [Mastez, 1981, p. 78]
>
> Volvo introduced 28 robots into an auto assembly line to make 695 spot welds, replacing 67 workers with a "handful of key staff" [Engelberger, 1980, p.66].
>
> At John Deere & Co., "Robots are handling 80-85 percent of the painting on each tractor - providing a labor saving of $300,000" [Vaccari, 1982, p. 131]
>
> "12 die casting machines can be serviced by six robots, all under the supervision of one operator" [Engelberger, 1980, p. 145]

To date, investments in robots have been made primarily to replace unattractive and often dangerous jobs in foundries and in welding and painting operations in auto and farm equipment assembly plants. Far larger labor impacts await the introduction of more sophisticated machine loading and assembly robots. Assembly robots with rudimentary visual and tactile sensors made by IBM are currently used in production by IBM, General Dynamics Corporation and Boeing [Marcus, 1983, p. D2]. As an indication of future developments, Hitachi has "publicly announced a task force of 500 key technology experts to fashion and install a standardized assembly robot with both visual and tactile sensors, microcomputer control and mobility, and projected a 60% robotization of its assembly processes by 1985" [Aron, 1982, p. 33].

While concerns over reliability and accuracy in the performance of work tasks and over the health and safety of workers may affect the decision to invest in robots, the overwhelming determinant is reduction of labor costs. As Engleberger, the president of the largest maker of robots, has said, "Industrials are mildly interested in shielding workers from hazardous working conditions, but the key motivator is the savings of labor costs by supplanting a human worker with a robot" [Engleberger, 1980, p. 103]. Ayres and Miller [1981, p. 25] also found that "survey respondents overwhelmingly ranked efforts to reduce labor cost as their main motivation" for installing robots. According to one executive, upper management sees the robot "as a way of magically substituting dependable machines for difficult-to-manage personnel" [Teresko, 1982, p. 38]. A survey of robot users [Frost and Sullivan, 1979] found that countering labor instability was a major factor in the decision to purchase robots.

These advantages have led market analysts to project annual growth rates of 30-40% for the robot market through 1990. Robot purchases increased from about $100 million in 1980 to $150 million in 1981. Despite the severity of the 1982 recession, robot sales reached $185 million in that year, a rise of 23% over 1981 [Hoard, 1983, p. 12]. The 1990 market has been estimated by most analysts to be about $2 billion and projections of the number of robots that will be sold in that year range from 21,000 to 31,000. After surveying these projections, a recent Upjohn Institute study concluded that a stock of 50-100,000 industrial robots would be in place in 1990 [Hunt and Hunt, 1982, p. 43]. This represents a significant increase over the estimated 4,700 industrial robots in use at the end of 1981 [Robot Institute of America, 1981, p. 3]. Unfortunately, these projections are usually made without specifying either the underlying assumptions concerning future economic conditions or the unit prices in which the estimates are expressed.

The increasing production and use of industrial robots in the U.S. will affect the capital, intermediate inputs and labor requirements of many industries. In this study, we consider only the diffusion of industrial robots of currently available technology. These include simple pick-and-place robots as well as programmable point to point and continuous-path robots with elementary visual or tactile capabilities. While most industrial robots are currently used to perform painting and welding tasks, in the future most robots will be used for machine tending and elementary assembly operations, and this increased scope is reflected in our projections.

We have assumed that industrial robots wil be used exclusively in manufacturing industries. According to a report of the Japan Industrial Robot Association (JIRA), manufacturing industries are expected to account for 87% of the demand for industrial robots in Japan as late as 1990 [Japan Economic Journal, 1981, p. 7]. Since Japan is pioneering the application of industrial robots to non-manufacturing tasks, it is likely that an even higher share of robots will be confined to the manufacturing sector in the United States. In this report we do not consider their future use in the mining and service sectors or in the home.

We assume an average 1979 robot price of $70,000, a figure that lies within the range implicit in the literature.[2] Our representation of the robot-producing sector, IEA #86, assumes that an average industrial robot includes certain peripheral equipment that is not manufactured but is passed along by the robot producer, increasing its price by 20% to $84,000.

Finally, since the industry was insignificant in size until the late 1970's, we assume that the Robotics sector first began producing industrial robots in 1977.

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[2] For example, dividing Aron's estimates of the value of the 1980 robot market by the number of robots sold gives a price of $78,000 [Aron, 1982, p. 32]. A similar calculation with Conigliaro's estimates produces a 1980 price of $68,966 [1981, p. 8].

The next section describes the capital (B matrix), intermediate input (A matrix), and labor (L matrix) requirements of the sector producing robots, IEA #86. These three columns are estimated for 1977 and, in the absence of additional information, are assumed to remain unchanged in future years. The following section describes the associated changes in the input structures of robot-using sectors for 1980, 1990 and 2000.

2. The Production of Robots

Capital Coefficients

Column #86 of the B matrix represents the amounts of the various kinds of plant and equipment that are required to increase the capacity of the Robotics sector by one unit. Since government data are not yet published for the Robotics industry and we were unable to survey robot manufacturers on this question, we based our estimates of these capital requirements on those of a similar industry. Although robots have much in common with machine tools, metal fabrication plays a key role in the production process of the Metalworking Machinery IEA #46 sector, while robots are manufactured primarily by assembling purchased components. The process used to manufacture computers is, like that of robotics, dominated by the assembly of relatively small parts (including electronic components). We used the 1972 column coefficients of the Computer sector (IEA #50) for the Robotics sector with a single exception: the computer requirements of the

Computer sector ($b_{50,50}$) were judged to be too large for the Robotics sector and this coefficient was replaced in column #86 by the coefficient that describes the purchases of computers by the Metalworking Machinery sector ($b_{50,46}$). The resulting column of the B matrix for the Robotics sector is shown in Table 4.5.

Table 4.5. Largest Capital Coefficients for the Robotics Sector in 1977 (Capital Requirements per Unit Increase in Capacity)

Code	Sector	Capital Coefficient
22	Other Furniture and Fixtures	.0253
45	Materials Handling Machinery and Equipment	.0974
46	Metalworking Machinery and Equipment	.0491
47	Special Industry Machinery and Equipment	.0522
48	General Industrial Machinery and Equipment	.0386
50	Electronic Computing and Related Equipment	.0114
51	Office Equipment, except IEA #50	.0080
52	Service Industry Machines	.0071
53	Electric Industrial Equipment and Apparatus	.1424
56	Radio, TV, and Communications Equipment	.0682
60	Miscellaneous Electrical Machinery and Supplies	.0078
61	Motor Vehicles and Equipment	.0617
65	Optical, Ophthalmical, and Photographic Equipment	.0208
71	Wholesale Trade	.0415
72	Retail Trade	.0093

Intermediate Input Coefficients

As in the case of the capital coefficients (B matrix), our estimates of the intermediate input requirements for the production of robots were based on data for a comparable sector in the A matrix for 1977. Despite the differences between the two sectors pointed out in the last section, we judged that Robotics (IEA #86) required a similar mix of materials and parts as Metalworking Machinery and Equipment (IEA #46) after making several major adjustments concerning purchases of industrial controls from IEA #53, steel from IEA #36, and peripheral equipment from IEA #45.

The controller is a key component of all robots and estimates given in various sources suggest 7% as the share of controls in the value of a robot. These controls are purchased from Electrical Industrial Equipment, IEA #53. We have assumed that the computer (microprocessor) component of a robot is included in the controller and consequently no direct purchases are made by Robotics from the Computer and Semiconductor sectors.

The use of steel per unit of output in the machine tool industry (.077) was significantly reduced to reflect the primary role of assembly of purchased parts in the robot manufacturing process. Purchases from Primary Iron and Steel Manufacturing, IEA #36, are assumed to be 2 cents per dollar of robots (0.02) in 1979 prices. This compares to a figure of 1.2 cents (.012) that can be derived from William Tanner's estimates [Hunt and Hunt, 1983, Table 4.3].

A large part of the costs of a fully installed robot consists of materials handling equipment and end-of-arm tooling. To represent these purchases, we assumed that the robotics industry purchases this equipment and passes it along to the buyer with the robot. From a study by Tanner and Adolfson [Hunt and Hunt, 1982, pp. 36-7], we estimate that 15% of the value of the robot (including the passed along robot-related equipment) consists of materials handling equipment (primarily conveyors, part orienters and guard rails) manufactured by sector IEA #45. In addition, 5% of the value of a robot is estimated to consist of end-of-arm tooling, purchased from the machine tool accessories portion of Metalworking Machinery, IEA #46. We assumed that the value of tools accompanying the robot that would otherwise have been purchased directly by robot-using sectors is negligible in size and made no compensating adjustments. With these changes, the inputs increase by 20% of the value of Robotics output. To compensate for this increase, the remaining coefficients were divided by 1.20.

As Table 4.6 shows, most of the intermediate inputs used in the manufacture of robots are assumed to be purchased from four sectors: IEA #53, Electrical Industrial Equipment (industrial controls and electric motors); IEA #49, Miscellaneous Machinery (hydraulic and pneumatic cylinders, and other parts); IEA #48, General Industrial Machinery (hydraulic and pneumatic motors and power transmission equipment); and IEA #36, Primary Iron and Steel. The other large inputs, IEA #45 (Material

Table 4.6. Intermediate Requirements for the Robotics Sector in 1977 (dollars per dollar, 1977 prices)

Code	Sector	Coefficients[a]
30	Petroleum Refining and Allied Industries	.0175
31	Rubber and Miscellaneous Plastic Products	.0042
35	Stone and Clay Products	.0042
36	Primary Iron and Steel Manufacturing	.0200[b]
37	Primary Nonferrous Metals Manufacturing	.0150
39	Heating, Plumbing and Structural Metal Products	.0050
40	Screw Machine Products and Stampings	.0050
41	Other Fabricated Metal Products	.0066
45	Materials Handling Machinery and Equipment	.1500[c]
46	Metalworking Machinery and Equipment	.0558[d]
48	General Industrial Machinery and Equipment	.0133
49	Miscellaneous Machinery, except Electrical	.0220
53	Electric Industrial Equipment and Apparatus	.0800[e]
55	Electric Lighting and Wiring Equipment	.0008
60	Miscellaneous Electrical Machinery and Supplies	.0008
61	Motor Vehicles and Equipment	.0017
64	Scientific and Controlling Instruments	.0025
67	Transportation and Warehousing	.0092
68	Communications, except Radio and TV	.0042
70	Electric, Gas, Water and Sanitary Services	.0083
71	Wholesale Trade	.0208
73	Finance	.0050
74	Insurance	.0017
75	Real estate and rental	.0075
76	Hotels, Personal and Repair Services exc. Auto	.0017
77	Business Services	.0208
78	Eating and Drinking Places	.0083
79	Automobile Repair Services	.0008

[a] The source of these coefficients is the 1977 IEA column for Metalworking Machinery, IEA #46, in 1979 prices unless otherwise noted. See text for further explanation.

[b] Reduced from .077.

[c] This represents the Materials Handling Equipment that is passed along to the purchaser.

[d] Includes .05 for end-of-arm tooling and .0058 for other inputs from Metalworking Machinery (IEA #46).

[e] Includes .07 for controls and .01 for other purchases from IEA #53.

Handling Machinery) and IEA #46 (Metalworking Machinery), consist of robot related equipment that is passed along to the using industry.

Labor Coefficients

Estimates of the labor required per unit of output in the Robotics industry were based on discussions with the personnel department of Unimation, Inc., a firm that accounts for almost half the robots produced in the U.S. Table 4.7 shows that four occupations account for most of the employment: Engineers (27%), Managers (9%), Clerical Workers (16%) and Assemblers (15%). The occupational composition reported by Unimation for 1982 was assumed for the robotics industry as a whole in 1977 and subsequent years.

Labor coefficients were computed by dividing employment in each occupation by an estimate of Unimation's 1982 output, $72 million. These coefficients were used to describe 1977 labor requirements and are shown in Table 4.7.

3. The Use of Robots: 1980, 1990, 2000

Capital Coefficients

The future use of robots in each sector is determined in the IEA database by two parameters. The first is an expansion coefficient, which measures the investment in robots required to expand capacity by one unit. The second is a modernization coefficient which describes the annual investment in robots per unit of output in the absence of expansion. Both types of capital coefficients were deduced

Table 4.7. Labor Coefficients for the Robotics Sector in 1982
(workers per million dollars of output, 1982 prices)

Code	Occupation	Occupational Composition[a]	Corresponding Labor Coefficients
1	Electrical Engineers	12.1%	1.10
2	Industrial Engineers	2.2	.20
3	Mechanical Engineers	4.4	.40
4	Other Engineers	8.3	.75
6	Computer Programmers	2.1	.19
7	Computer Systems Analysts	.9	.08
8	Other Computer Specialists	.3	.03
9	Personnel & Labor Relations Workers	.3	.03
16	Other Professional, Technical	8.2	.74
17	Managers, Officials, Proprietors	9.0	.82
18	Sales Workers	4.0	.36
19	Stenographers, Typists, Secretaries	5.6	.51
20	Office Machine Operators	.9	.08
24	Other Clerical	9.2	.83
26	Electricians	.9	.08
29	Foreman, nec	.8	.07
30	Machinists	2.3	.21
32	Other Metal Working Craft Workers	1.5	.14
33	Mechanics, Repairers	.8	.07
39	Assemblers	14.7	1.34
40	Checkers, Examiners, Inspectors	2.8	.25
41	Packers and Wrappers	.4	.04
42	Painters	.7	.06
43	Welders, Flame Cutters	.9	.08
46	Other Operatives	5.6	.51
48	Janitors and Sextons	.4	.04
52	Laborers	.7	.06
	Total	100.0	9.07

[a] Reported by Unimation, Inc. for 1982.

from estimates of the future stocks of robots held by each sector per unit of output -- an average robot to output ratio -- in the absence of expansion.

The estimates of average robot capital coefficients were developed in 3 stages. First, the 1980 stock of robots was estimated for each robot-using industry. Second, the increase in the aggregate robot stock required to produce the same level of output using the average technology in place in 1990 was projected. Finally, these 1980 and 1990 stocks were distributed to each of 43 robot-using industries.

Because of the small number of industrial robots in use before 1977, we began by estimating average robot capital coefficients (the stocks of robots held per unit of output for each using industry) for 1980, and this serves as our base year for the projections to 1990 and 2000. At $84,000 each, the estimated 2600 robots in use in 1980 represented a stock of $218.4 million.

There is at present no systematic collection of data on the stocks of robots held by industry. However, a study by Frost and Sullivan used survey data to estimate the sales of robots to 13 manufacturing industries and industry groups for 1979 [Frost and Sullivan, 1979, p. 135]. A recent Society of Manufacturing Engineers Delphi study on robotics presented estimates of the share of the robot market purchased by the Auto and Aerospace industries and the Casting and Foundry, Electrical and Electronic, Heavy Manufacturing and Light Manufacturing industry groups [Smith and Wilson, 1983, p. 48].

These two sources were supplemented by information in trade journals to estimate the distribution of industrial robots by sector.

These data are assembled for 1980 in Table 4.8 which shows that primary metals and metal fabrication industries (IEA #36-41) account for 35%, and auto and farm equipment producers hold another 23% of the stock of robots. Almost 14% are held by producers of electrical equipment (#53-56), and 5.3% are used for aircraft production. The estimated shares for 1990 and 2000 are also shown in this table (the changes from the 1980 distribution are explained below). The average coefficients for 1980 were computed by dividing each component of the 1980 vector of robot stocks (the shares multiplied by the aggregate stock) by the corresponding component of the vector of 1980 outputs, all in 1979 prices.

Despite a stagnant economy, investment by manufacturers in robots has grown rapidly in the last few years. In our projections we assume that under the high diffusion scenario, S3, the average use of robots per unit of output will grow at a real rate of 25% a year. Under Scenario S2, a 15% rate of growth is assumed. These estimated growth rates are used to compute the stock of robots that will be required in 1990 to produce base year (1980) levels of output.

Table 4.8. Distribution of Robots by Sector in 1980, 1990 and 2000

(percentages)

Code	Sector	1980	1990, 2000
12	Ordnance and Accessories	1.76%	2.64%
13	Food and Kindred Products	1.33	4.00
21	Household Furniture	.27	.40
22	Other Furniture and Fixtures	.27	.40
26	Chemicals and Selected Chemical Products	1.40	2.10
27	Plastics and Synthetic Materials	.50	.75
28	Drugs, Cleaning and Toilet Preparations	.62	.93
29	Paints and Allied Products	.13	.20
31	Petroleum Refining and Allied Industries	1.76	2.64
34	Glass and Glass Products	.22	.33
35	Stone and Clay Products	1.11	1.66
36	Primary Iron and Steel Manufacturing	12.40	6.20
37	Primary Nonferrous Metals Manufacturing	8.10	4.00
38	Metal Containers	1.76	.80
39	Heating, Plumbing and Structural Metal Products	4.60	2.30
40	Screw Machine Products and Stampings	3.54	1.77
41	Other Fabricated Metal Products	4.60	2.30
42	Engines and Turbines	.58	.87
43	Farm and Garden Machinery	3.10	2.80
44	Construction and Mining Machinery	.93	1.40
45	Materials Handling Machinery and Equipment	.26	.40
46	Metalworking Machinery and Equipment	.62	.90
47	Special Industry Machinery and Equipment	.49	.74
48	General Industrial Machinery and Equipment	.88	1.32
49	Miscellaneous Machinery, except Electrical	.53	.80
50	Electronic Computing and Related Equipment	1.60	2.40
51	Office Equipment	.60	.90
52	Service Industry Machines	.60	.90
53	Electric Industrial Equipment and Apparatus	2.65	4.00
54	Household Appliances	4.73	7.10
55	Electric Lighting and Wiring Equipment	1.70	2.60
56	Radio, TV, and Communications Equipment	4.73	7.10
57	Electron Tubes	.22	.33
58	Semiconductors and Related Devices	.71	1.10
59	Electronic components, nec	1.20	1.80
60	Miscellaneous Electrical Machinery and Supplies	1.70	2.50
61	Motor Vehicles and Equipment	20.00	18.00
62	Aircraft and Parts	5.31	4.80
63	Other Transportation Equipment	1.50	2.25
64	Scientific and Controlling Instruments	.09	.14
65	Optical, Ophthalmical, and Photographic Equipment	.09	.14
66	Miscellaneous Manufacturing	.22	.33
86	Robotics Manufacturing	.10	.15
	Total	100.00	100.00

The next step was to distribute the 1990 stocks among robot-using industries. The first generation of industrial robots has been concentrated in the foundry and casting (IEA #36-41), Farm and Garden Machinery (IEA #43), Motor Vehicles (IEA #61) and Aircraft (IEA #62) industries (see Table 4.8). However, with the application of robots to assembly, materials handling and machine tending, the shares of the aggregate stock held by these industries can be expected to fall and the sectoral distribution of installed robots should become more equal. Industries using small batch techniques (IEA #44-53) to produce metal parts, equipment and machinery will increase their use of robots for tool changing and materials handling. The shares of aggregate robot stock held by industries whose production processes are characterized primarily by assembly and packaging tasks (e.g., Household Appliances, IEA #53, Radio and TV, IEA #56, and Food and Kindred products, IEA #13) can also be expected to increase in coming years.

As shown in Table 4.8, the proportion of robots held by sectors IEA #36-41 in 1990 and 2000 is half the 1980 value, while Farm and Garden Machinery (IEA #43), Aircraft (IEA #62) and Motor Vehicles (IEA #61) each decline by 10%. The proportions held by all other industries are assumed to increase by 50%, with the exception of Food Products (IEA #13), which rises by 300% in anticipation of the widespread application of robots to materials handling and packaging which play particularly important roles in this sector.

The product of these sector shares and the projected aggregate robot stocks yields estimates of the average use of robots by sector for a given (1980) level of output in 1990.

The annual increase for each sector in the stock of robots between 1980 and 1990 that will be used to produce a given (1980) level of output can now easily be computed. These modernization (labor replacement) coefficients[3] describe the investment requirements in the absence of expansion and are assumed to grow through 1990 and then to remain at these 1990 values through 2000.

The capital coefficients governing expansion -- row #86 of the B matrix -- were derived from these (average) ratios of robot stock to sectoral output. For 1980, we assume that the capital coefficients were the same as the average coefficients for that year. For 1985 the capital coefficients (robot requirements in new plants) are assumed to be the same as the average coefficients (robot requirements in the average plant) for 1990. As a result of improvements in the current generation of robots and an increased awareness of their capabilities, these capital coefficients are assumed to reach their maximum values in 1985 and to remain constant thereafter.

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[3] The corresponding reductions in sectoral labor coefficients are described below.

Intermediate Input Coefficients

The increasing use of industrial robots is likely to have some effect on the use of paint per unit of output, and this is the only intermediate input considered here. Robots can be programmed to apply an identical coat of paint to each object, with the result that "in spray painting operations it is not uncommon to achieve a 10 to 30 percent savings in materials" [Teresko, 1982, p. 39]. According to The American Machinist [Vaccari, 1982, p. 134], a Deere & Co. spokesperson claimed that the use of robots in the painting of tractors has reduced paint consumption by about 13%.

These estimates of the savings in paint apply only to the portion of the painting tasks that has been robotized in each industry. Painting robots are most easily introduced into large scale, standardized operations. Thus, some workers operate automatic machinery for which robots are not applicable, while others use spray guns on small, specialized jobs that will not be robotized.

The paint (IEA #29) coefficients for robot-using industries were projected according to the equation

$$a_{29j}^{t} = (1-\alpha\beta^{t})\, a_{29j}^{77} \qquad (6)$$

where a_{29j}^{t} is the paint used per unit of output of industry j in time t, a_{29j}^{77} is the paint coefficient in 1977 (the base year), β^{t} is the portion of painting tasks performed by robots

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[3] The corresponding reductions in sectoral labor coefficients are described below.

in time t, and α is the percent savings in paint that follows from the use of robots. The savings in paint α was assumed to be 20%, and the portion of painting tasks robotized under each scenario was based on rough estimates of the share of the painters that will be replaced by robots in 1990 and 2000. We assumed that 15% of the painting tasks in 1990 and 25% in 2000 would be performed by robots under Scenario S2. Under Scenario S3, these figures were assumed to be 25% and 40%, respectively. Table 4.9 summarizes these assumptions and shows that the new paint coefficients range from 97% of the 1977 coefficient in 1990 under Scenario S2, to 92% under S3 in 2000.

Table 4.9. Impact of Robots on Paint Requirements per Unit of Output in 1990 and 2000

	Scenario S2		Scenario S3	
	1990	2000	1990	2000
Proportion of Paint Saved (α)	.20	.20	.20	.20
Proportion of Painting Tasks Performed by Robots (β)	.15	.25	.25	.40
Paint Coefficient as Proportion of 1977 Coefficient	.97	.95	.95	.92

[a] Computed as $(1-\alpha\beta^t)$ in Equation (6)

Labor Requirements

The growth in the use of robots will lower the labor requirements for a number of production occupations while increasing the need for Robot Technicians. These effects are directly associated with the number of robots in place, which is computed endogenously by the IEA model in each year from 1977 to 2000. Changes in labor requirements for six occupations are estimated through the use of a matrix of "displacement" coefficients, representing the number of workers in each occupation and each sector displaced by a million (1979) dollars worth of robots. These coefficients were computed by weighting a general displacement rate (3 workers displaced per robot) by the proportions of a given sector's stock of robots assigned to applications areas that correspond to 6 production occupations, divided by the average unit price of a robot, $84,000. The same procedure was followed for Robot Technicians, except that the entries in the corresponding row of the displacement matrix have the opposite sign from the other occupations.

We estimated the share of the robots held by each sector that will be devoted to five areas of application: welding, painting, assembly, machine tending and miscellaneous materials handling. The first four of these applications affect workers in the following IEA catgories: Welders and Flame Cutters (LAB #43), Painters (LAB #42), Assemblers (LAB #39) and Other Operatives (semiskilled machine operators) (LAB #46). Materials handling robots were assumed to replace two categories of workers, Packagers and Wrappers (LAB #41) and Laborers (LAB #52).

The results of the most recent attempt to project the share of robots by application to 1990 [Hunt and Hunt, 1982, p. 42] are reproduced in Table 4.10. Unfortunately, this study distinguished only the auto industry and "Other Manufacturing." We assume that in 1990 Farm and Garden Machinery (IEA #43), Aircraft (IEA #62), and Other Transportation Equipment (IEA #63) will use the same share of robots in each application area as the Upjohn Institute study [Hunt and Hunt, 1982, p. 42] projects for Motor Vehicles (IEA #61). For most of the remaining sectors, materials handling robots (i.e., those used primarily for packaging and in automated warehouse systems) were assumed to make up 10% of each industry's

Table 4.10 U.S. Robot Population by Application in 1990

Application	Autos Range of Estimates Low	 High	All Other Manufacturing Range of Estimate Low	 High	Total Range of Estimate Low	 High
Welding	3,200 (21.3%)	4.100 (16.4%)	5,000 (15.7%)	10,000 (13.3%)	8,700 (17.4%)	14,100 (14.1%)
Assembly	4,200 (28.0%)	8,800 (35.2%)	5,000 (14.3%)	15,000 (20.0%)	9,200 (18.4%)	23,800 (23.8%)
Painting	1,800 (12.0%)	2,500 (32.0%)	3,200 (9.1%)	5,500 (7.3%)	5,000 (10.0%)	8,000 (8.0%)
Machine Loading/ Unloading	5,000 (33.3%)	8,000 (32.0%)	17,500 (50.0%)	34,000 (46.0%)	22,500 (45.0%)	42,000 (42.0%)
Other	800 (5.3%)	1,600 (6.4%)	3,800 (10.9%)	10,500 (14.0%)	4,600 (9.2%)	12,000 (12.1%)
Total	15,000	25,000	35,000	75,000	50,000	100,000

Source: [Hunt and Hunt, 1982].

installed robots. In the food, chemicals, glass and stone processing sectors (IEA #13, 26-29, 31, 34-35) the remaining share (90%) of the robot stock was allocated entirely to machine tending applications. In primary metal processing (IEA #36, 37), 10% of the robots were assigned to welding, reducing those in machine tending operations to 80%. The remaining metalworking sectors (IEA #12, 38-42, 44-49, 52) were assumed to use half their robots for machine tending, 20% for welding and 20% for assembly and 10% for materials handling tasks. Finally, those industries specializing in assembling operations (IEA #53-59, 64 and 65) were assumed to use 30-60% of their robots for assembly.

Recent evidence from Japan suggests that among the most advanced robots currently in use, displacement rates of 2-4 workers per shift are possible. A study published by the Japan Industrial Robot Association, [1982] includes the following examples:

> Arc welding system for two types of Farm Appliance Components. . . . The number of workers required in this process has been reduced from 3 to 1 [p. 352].
>
> Automatic System to continuously operate five die cast machines with only one worker. . . . The operation of five die cast machines needed five workers - one for each machine before the robot was introduced. Now they can be satisfactorily run by only one person [p. 364]. System for automatically piling up and cooling down aluminum ingots cast by a continuous casting machine. . . . Formerly, four workers had been needed to pile up ingots, but one operator is now able to attend to the entire line satisfactorily [p. 374].
>
> Full automatic mounting system for semiconductor chips. . . . One automated machine can perform work which, if carried out manually as before, would have required 6 workers (p. 234).

These examples appear to lie at the high end of the spectrum of displacement rates appearing in the literature. Displacement rates of 1.5 workers per shift in die casting and two workers per shift in press work are cited in [Engelberger, 1980, p. 153, 145]. A Battelle Memorial Institute survey of five German factories [Ayres and Miller, 1983, p. 73] states that the average displacement per robot is 1.5 workers per shift. Based on 1.5 workers per robot and 2-shift operations, we assumed that three workers are displaced per robot.

The literature also suggests that one robot technician will be required for every six robots per shift [Freedman, 1982, p. 34; Engelberger, 1980, p. 145]. With two shift operations, two robot technicians would be required for every 6 robots.

These rates were used to compute the number of workers displaced (or employed in the case of Robot Technicians) in each occupation per million dollars of a given sector's robot stock. Displacement (employment) coefficients are presented in Table 4.11 for three sectors. They indicate that Other Operatives (semiskilled machine operators) (LAB #46) are those most affected by robots in the Primary Iron and Steel sector, while Assemblers (LAB #39) are most affected in Household Appliances. Direct displacement by robots in the motor vehicles industry is greatest for Assemblers, Machine Operators and Welders (LAB #43).

Table 4.11. Direct Labor Displacement by Robots for Three Sectors (workers per million dollars of robots, 1979 prices)

Code Occupation	Primary Iron and Steel (#36)	Household Appliances (#54)	Motor Vehicles (#61)
39 Assemblers	0	-14.30	-10.10
41 Packers and Wrappers	- 1.45	- 1.43	- .72
42 Painters	0	- 1.78	- 4.33
43 Welders and Flame Cutters	- 3.63	- 3.57	- 7.58
46 Other Machine Operatives	-28.50	-12.50	-11.90
47 Robot Technicians	3.97	3.97	3.97
52 Laborers	- 2.18	- 2.14	- 1.08

Most industry observers expect that the accuracy and dependability that robots bring to production will significantly affect the need for inspectors and checkers. We did not have enough information to apply the above methodology to inspectors. Instead, we based our estimates of the change in inspector requirements on the results of two recent studies of the labor impacts of robots. The Delphi Forecasts on robots conducted by the Society of Manufacturing Engineers [Smith, and Wilson, 1982] concluded that the amount of inspectors "who will actually be displaced by robots" will be 8% in 1990 and 15% in 1995. Based on a survey of robot users, a Carnegie-Mellon University study concluded that Level 1 robots ("similar to those on the market today") could do 13% of the jobs currently done by inspectors in metalworking industries [Ayres and

Miller, 1981, p. 29]. Using these figures as a rough guideline, we assumed that the Inspectors (LAB #40) required per unit output in 1977 would fall by 8% by 1990 under Scenario S2 and 13% under S3. By 2000 we assumed a decline of 20% under S2 and 30% under S3.

D. CNC Machine Tools

1. Overview of the Technology

Machine tools are power driven machines designed to cut and form metal. Metal cutting machine tools include turning (lathe), boring, drilling and milling machines, while metal forming machine tools consist primarily of presses, forges, and bending, punching and forming machines. The most significant innovation in machine tool design in this century took place in the 1950's with the development of numerically-controlled (NC) machine tools. Whereas the use of conventional tools was dependent upon the operator, NC tools could be programmed to follow a predetermined sequence of steps. As Duke and Brand have written, NC "machine tools are controlled by instructions which are programmed and then punched on a tape. Information from the tape is converted into instructions which position the tools with respect to the work piece; no templates, drill jigs, or stops are used and manual operation is not necessary" [Duke and Brand, 1981, p.31].

The potential advantages offered by NC equipment are considerable. Surveys of NC users have been conducted by an MIT group headed by Robert T. Lund and by Frost and Sullivan, a market research firm. Both found that NC tools reduced machining time per part, the amount of scrap produced, and set-up time. In addition, both surveys found that the increase in management control of the work pace was significant [Lund, 1978, p. 27; Frost and Sullivan, 1982, p. 196]. However, despite expectations by many industry observers in the late 1950's and early 1960's that these advantages would cause NC tools to revolutionize the production process in metalworking industries, only 2% of the machine tools in these industries had numerical controls by 1977.

The failure of the market for NC tools to take off in the 1960's can be attributed to the high initial investments (both in the tools and in personnel) that were required, maintenance problems, programming inflexibility, and manager and worker resistance to change [Lund, 1977, p. H-56]. By the late 1970's these disincentives to the diffusion of the NC tools began to disappear. Between 1963 and 1973 the NC share of the total number of machine tools shipped fluctuated between .6 and 1.0%. This figure rose to 1.6% in 1977, 2.1% in 1979, and 2.7% in 1980. Between 1972 and 1980, the NC share of the value of shipments of machine tools almost doubled, from 13.4% to 26.2% [Lund, 1977, p.H-61; National Machine Tool Builders Association, 1981, pp. 93, 100].

An increasing familiarity with programmable machines, improvements in quality, and lower relative NC machine costs help to explain this rapid increase in the NC share of the market. At least as important, however, was the development of computer-numerically controlled (CNC) machinery in the

1970's. By 1981, almost all the NC tools on the market were of the CNC variety. The replacement of taped instructions with a CRT (visual display) terminal and programming capability at the machine represented a significant advance in the technology of machine tool controls because it widened the potential sphere of NC tool applications: first, to large plants that formerly used less flexible technologies (e.g., transfer lines); and second, to small plants, where the older generation of NC equipment was viewed as too inflexible. The use of CNC machines reduced the programming inflexibility and maintenance problems associated with tapes, while the increasing substitution of microprocessors for minicomputers narrowed the CNC to NC price differential.

The most important long-run advantage of CNC tools is their potential for linkage with other programmable machines on the plant floor and to a hierarchy of computers throughout the firm. A recent OECD study has emphasized the significance of this advance over the older generation of NC tools:

> When a part is machined using CNC, a program is fed into the computer. . . With the help of such a program, which is easy to change and which can be easily found in the memory, it is possible for a single operative of average skill to produce the part that has to be machined. . . Combined with automatic handling systems (of the industrial robot type) it will be able to compete with transfer machines [OECD, 1981, pp. 25, 26].

The substitution of CNC for conventional tools is certain to have significant effects on the structure of production in the metalworking industries. The following parts of this section describe the procedures that were used to estimate changes in the capital (B matrix), intermediate input (A matrix), and labor requirements (L matrix) per unit of output that can be expected to occur as this substitution takes place. Scenarios S2 and S3 are distinguished by the extent of the substitution projected for 1990 and 2000.

2. The Production of Machine Tools, 1990 and 2000

As CNC tools are substituted for conventional machines, the input requirements of the producers of machine tools (Metalworking Machinery, IEA #46) will be affected. In this study, we have limited these effects to the increase in the purchases of CNC controls.

In the early stages of CNC development, the controller was a minicomputer. A 1978 MIT study describes a CNC tool in which "the computer is located on the shop floor alongside the machine, and machine instructions may be programmed or edited at the machine" [Lund, 1978, p. 4]. According to an unpublished BLS case study, the cost of the minicomputer was somewhat less than 20% of the total CNC machine tool price. However, as microprocessors have replaced the minicomputer, the cost of the controller has dropped to about 10% of the total price [Frost and Sullivan, 1981, p. 4].

Although the principal manufacturers of CNC controls are electronics and machine tool firms such as General Electric, Allen-Bradley, and Cincinnati Milacron, the establishments from which they are purchased are classified in the input-output tables as Industrial Controls, a component of the broader sector, Electric Industrial Equipment and Apparatus (IEA #53).

Our estimate of the purchases of industrial controls by Metalworking Machinery in year t was calculated using the equation

$$a^{t}_{53,46} = \alpha\beta^{t} + (1-\gamma)\, a^{77}_{53,46} \qquad (7)$$

where α is the ratio of the value of CNC control units (purchased from sector 53) to the value of the CNC machine tool output of sector 46, β^t is the ratio of the value of the CNC machine tool output to the total output of sector 46 in year t, $a_{53,46}$ is the value of the purchases of Electric Industrial Equipment (IEA #53) by the Metalworking Machinery industry (IEA #46) per unit of the latter's output, and γ is the share of industrial controls in the purchases of IEA #53 output by IEA #46. The expression $\alpha\beta^t$ gives the value of the CNC controls in total machine tool output, while the second term represents the output of IEA #53 -- minus controls -- that is purchased by IEA #46 per unit of the latter's output.

The share of the CNC control unit in the cost of the machine (α) was estimated to be 10% in 1979 prices. The estimated share of CNC machine tools in the total machine tool output (β^t) was based upon its past rates of growth of this ratio. From 1972 to 1977 the annual rate was 8.6%; over the 1977 to 1980 period, it was 9.0%. Assuming the 9% annual rate through 1990 for scenario S2, the 26.6% CNC share of the market in 1980 would increase to 63%. Under Scenario S3, a 12% annual increase was assumed, resulting in a CNC share of 83% by 1990. For the year 2000, the CNC share under Scenario S2 was assumed to be 85% and under Scenario S3, 95%. From the 1977 input-output tables, $a^{77}_{53,46}$ is .019, and $\gamma a^{77}_{53,46}$ is .012.

Given these data, the coefficient $a_{53,46}$ increases to .092 by 2000 under Scenario S2 and to .102 under Scenario S3. These numbers are shown in Table 4.12.

Table 4.12. Impact of CNC Controls on the Purchases of Electrical Industrial Equipment (IEA #53) by Metalworking Machinery (IEA #46) in 1990 and 2000 (dollars per dollar, 1979 prices)

	Scenario S2		Scenario S3	
	1990	2000	1990	2000
Share of the CNC Controls in Output of IEA #46 ($\alpha\beta^{t}$)	.063	.085	.083	.095
Elecrical Equipment (IEA #53) Requirements per unit of output Metalworking Machinery (IEA #46), except Industrial Controls $(1-\gamma)\ a^{77}_{53,46}$	.007	.007	.007	.007
Electric Industrial Equipment (IEA #53) Requirements per Unit Output of Metalworking Machinery (IEA #46 in Year t ($a^{t}_{53,46}$)	.070	.092	.090	.102

3. The Use of Machine Tools: 1977, 1990, 2000

Capital Coefficients

Metalworking Machinery (IEA #46) is classified as sector #354 in the Standard Industrial Classification and includes nine 4-digit SIC industries that mainly produce machine tools and the equipment that is used in conjunction with them (tools and dies, machine tool accessories). This section describes the procedures used to estimate the capital coefficients governing the investment demand for the output of IEA #46 for expansion -- i.e., row #46 of the B matrix -- for 1977, 1990 and 2000.

Capital coefficients (b_{46j}) for 1977 were developed by computing the increase in the average capital in place per unit of output between 1972 and 1977 and applying this factor to the 1972 capital coefficients described in Chapter 3.

The Bureau of Economic Analysis (BEA) has recently published time series data of capital stocks held in the U.S. which include estimates of the aggregate value of metalworking machinery [U.S. Department of Commerce, 1982, p. 170], estimated at $58,664 million (in 1972 prices) in 1977. (Gross rather than net stocks were chosen since the physical deterioration of metalworking machinery is considerably more gradual than its economic depreciation.) This figure was deflated to 1979 dollars and transformed to producer prices by deducting the share of trade and transportation margins given in [U.S. Department of Commerce, 1980, p. A.23] for 1972.

4.50

The share of this aggregate stock ($125,230 million) held by the metalworking sectors (85%) was distributed among them on the basis of information derived from the 1976-78 American Machinist Inventory of Metalworking Equipment [American Machinist, 1978, pp. 136-7]. We assumed that the value of the stock was proportional to the number of tools held, adjusted for the sector's share of numerically controlled (NC) tools. The average 1979 price of an NC tool was estimated to be eleven times that of a conventional tool [National Machine Tool Builders Association, 1981, pp. 93, 100, 106] and the value of machine tools in use in a given industry was adjusted to reflect this price differential. The value of the machine tool stock held by each sector was estimated by the equation

$$k_j = (11m_j^n+m_j^c)p^c \qquad (8)$$

where k_j is the value of machine tool units in use in industry j, m_j^n is the number of numerical controlled machine tool units in use, m_j^c is the number of conventional tools in use, and p^c is the unit price of conventional tools.

About 85% of the machine tools in use in the U.S. in 1978 were held by metalworking industries [National Machine Tool Builders Association, 1981, p. 256]. The remaining 15% was allocated to the non-metalworking industries with the largest investment in machine tools in 1972 (the most recent date for which this information was available): Livestock (IEA #1), Other Agricultural Products (IEA #2), Construction (IEA #11), Lumber and Wood Products (IEA #19), Rubber (IEA #31), Glass (IEA #34) and Stone and Clay Products (IEA #35).

Average coefficients were computed by dividing each industry's stock of metalworking machinery by its output. The same procedure was used to compile 1972 average coefficients, and the ratios of the 1977 to 1972 coefficients were applied to the capital coefficients appearing in the B matrix for 1972 to derive incremental capital coefficients for 1977.

For the projection of capital coefficients, we assumed that machine tools can be subdivided into two categories, conventional and CNC. Thus, NC equipment was not distinguished from the CNC variety, a reasonable simplification since as early as 1979, 80% of the NC market consisted of CNC tools [Teresko, 1979, p. 103],reaching 95% and by 1980 [Frost and Sullivan, 1981].

We define b_{46j} as the stock of metalworking machinery required to produce a unit of output of sector j (k_{46j}/x_j) in plants using the newest technology. The stock is in fact composed of a mix of conventional and NC machinery ($k_{46j} = k^c_{46j} + k^n_{46j}$), and we can define separate capital coefficients in terms of the amount of each type of capital required to produce the corresponding portion of output: $b^c_{46j} = k^c_{46j}/x^c_j$ and $b^n_{46j} = k^n_{46j}/x^n_j$. Next, the metalworking machinery capital coefficient for industry j can be written as the sum of the conventional coefficient and the CNC coefficient, each weighted by the share of the sector's output produced using the corresponding technology:

$$b_{46j} = b^c_{46j}\ (x^c_j/x_j) + b^n_{46j}\ (x^n_j/x_j) \qquad (9)$$

Finally, Equation (9) can be rewritten as

$$1/b_{46j} = (1/b^{c}_{46j})\,(k^{c}_{j}/k_{j}) + (1/b^{n}_{46j})\,(k^{n}_{j}/k_{j}), \qquad (10)$$

which allows us to replace estimates of the future share of the ouput produced with CNC tools with estimates of the CNC portion of the machine tool stock. To solve Equation (10) for b_{46j} for some year t, we must know the conventional and CNC capital coefficients (b^{c}_{46j} and b^{n}_{46j}, respectively) as well as the shares of CNC and conventional machine tools in the total value of the machine tool stock in new plants in sector j at time t, (k^{n}_{46j}/k_{46j}) and (k^{c}_{46j}/k_{46j}).

The value of NC machine tools in use accounted for 10.2% of the total machine tool stock held by metalworking industries in 1972, and rose to 22.2% in 1977. Under Scenario S2 the NC (CNC) share of the machine tool stock required for expansion was assumed to increase further to 42% in 1990, an average annual rate of increase from 1977 to 1990 of 5%. Under Scenario S3 a rate of 10% was assumed, which results in a 77% CNC share in 1990. In the year 2000, CNC tools are assumed to account for 85% of the machine tool stock under Scenario S2 and 95% under Scenarios S3 and S4. These levels of diffusion are assumed to be attained in each machine tool-using industry.

Finally, we need to evaluate the conventional and NC captial coefficients appearing in Equation (10). We assumed that a CNC tool does the work of 4.5 conventional tools, which lies within a commonly cited range of estimates found in the literature. For example, according to one source, "a CNC flame cutter does the work of 3-5 conventionally operated flame cutters" [Iron Age, 1980, p. 16]. Another publication cites a U.S. firm that replaced 12 conventional lathes with 3 NC lathes [Real, 1980, p. 53], and an MIT study reports capacity ratios of 3:1 and 5:1 [Lund, 1978, p. 25]. In addition, the increasing use of machining centers (multi-purpose milling machines) will tend to increase these ratios and, consequently, we chose a figure (4.5) at the high end of this range of estimates. According to [Frost and Sullivan, 1982], sales of NC machining centers will outpace other NC tools and will account for 33% of the total machine tool market by 1990.

Recalling that the unit price of an NC tool is eleven times that of a conventional one in 1979 prices, we can write

$$b^{n}_{46j} = 11/4.5\ b^{c}_{46j} = 2.44\ b^{c}_{46j}. \qquad (11)$$

For $b^{c}_{46,j}$ we used the 1977 metalworking machinery coefficients, adjusted to reduce the effect of differences in the relative share of NC tools held by sector on the coefficients in that year. While only 1.6% of the total machine tools in use in 1977 were numerically controlled, the proportion varied widely among industries, from 4.4% in Aircraft to 0.3% in Screw Machine Products [American Machinist, 1978, p. 137].

Table 4.13 shows that these procedures produce 1990 Metalworking Machinery capital coefficients that are 33% larger than in 1977 under Scenario S2 in 1990 and 1.28 times larger in 2000 under Scenario S3.

Table 4.13. Impact of CNC Controls on Metalworking Machinery Capital Coefficients in 1990 and 2000

	Scenario S2		Scenario S3	
	1990	2000	1990	2000
CNC Share of Metalworking Machinery in New Stocks (k^n/k)	.42	.85	.77	.95
Metalworking Machinery Capital Coefficient as Proportion of 1977 Coefficient	1.33	2.01	1.83	2.28

Intermediate Input Coefficients

While the primary advantages of CNC tools lie in higher rates of machine throughput (output per hour of operation), vastly reduced labor requirements, and their ability to be linked with other programmable machines (thereby increasing the productivity of the entire process), the savings in materials through lower scrap rates is also often cited as a key factor justifying the purchase of these tools. (See [Lund, 1977, p. 27; Real, 1980, p. 138]).

As CNC tools are substituted for conventional tools, the use of steel per unit of output of the metalworking industries should decline. We estimated the new steel coefficients (a^{t}_{36j}) with the equation

$$a^{t}_{36j} = a^{77}_{36j} - \alpha\gamma s_j \qquad (13)$$

where α is the percent reduction in steel scrap, γ is the proportion of metalworking operations using CNC tools, s_j is the steel scrap produced per unit of output by industry j, and a_{36j}^{77} is the steel used per unit of output in 1977.

We assumed that the use of CNC tools can reduce steel scrap (waste from machining as well as the steel embodied in defective products) by 70% (α=.7). We estimated that the production of scrap amounts to 25% of the value of the steel purchased for use with conventional equipment ($s_j = .25a_{36j}^{77}$), which is somewhat higher than the Office of Technology Assessment [U.S. Congress, 1979, p. 27] estimate of 17.6% for the losses from machining and the scrap that is purchased from "end-product manufacture." The parameter γ was estimated by the share of output produced by CNC tools in 1990 and 2000 under each scenario. This share was calculated from the projected CNC portion of the machine tools required for expansion (see the first row of Table 4.15) and the output differential between CNC and conventional tools (4.5).[4]

These parameters and the resulting steel coefficients are given in Table 4.14. As a result of the reduction in steel scrap, we estimate that these coefficients decline to 88% of their 1977 size by 2000 under Scenario S2, and to 84% under Scenario S3.

Labor Coefficients

The machining occupations are those most affected by the substitution of CNC for conventional tools. These include

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[4] For example, if 6% of the machine tools required for expansion are CNC, the share of the output produced with CNC tools is $\frac{(.06)4.5}{(.06)4.5 + .94} = .223$.

Machinists (LAB #30), Tool and Die Makers (LAB #31), and the metalworking operatives (included in Other Operatives, LAB #46).

Table 4.14. Impact of CNC Tools on Steel Requirements in 1990 and 2000

	Scenario S2		Scenario S3	
	1990	2000	1990	2000
Reduction in Steel Scrap Attributable to CNC Tools (α)	.70	.70	.70	.70
CNC Share of Metal-working Operations (γ)	.22	.70	.58	.90
Scrap Produced with Conventional Tools (s_j) as Proportion of a_{36j}^{77}	.25	.25	.25	.25
Steel Coefficient (a_{36j}) as a proportion of coefficient in 1977	.96	.88	.90	.84

The labor coefficients for these three metalworking occupations were projected with the equation

$$l_{qj}^{t} = (1- \alpha^{t}\beta^{t})\ l_{qj}^{77} \qquad (14)$$

where α^t is the CNC share of the machine tools stock (in units) in year t, β^t is the proportion of labor saved per unit of output through the use of CNC tools, and j refers to each of the 33 metalworking sectors (IEA #12, 22, 35-49, 51-57, 59-66, 86).

The share of CNC tools in the total stock of machine tool units (α) increased at an average annual rate of 19% between 1977 and 1980. Under Scenario S2 we assume that this share increases at an annual rate of 8% between 1980 and 1990, from 2.7% to 6.0%. Under Scenario S3 a rate of increase of 24% was assumed, bringing the CNC share to 23%. In the year 2000 CNC tools are assumed to be 34% of the total stock under S2 and 65% under S3. Thus, under Scenario S3 the rate of increase in the CNC share of machine tool units increases most rapidly between 1980 and 1990, while under Scenario S2 the rate of increase is most rapid between 1990 and 2000.

The labor savings per unit of output obtained with the use of CNC tools (β^t) results from two factors, the output differential per tool (γ^t), and the differential in labor requirements per tool (ϕ^t). Each CNC tool is assumed to be 4.5 times as productive as a conventional tool (γ) for reasons given in the preceding part of this section.

The following passage illustrates why the use of CNC tools will also reduce the time required of operators on each machine (ϕ^t):

> In machining centers, complex shapes may be made by mounting cutting tools of varying sizes and power configurations on a single spindle. The cutting tools then are automatically changed by transfer arms, which also store the tool. The automatic tool changes take only a few seconds; formerly several minutes of an operator's time were required. Machine Machining centers also eliminate the need to design, build build, and store the jigs and fixtures needed by single-purpose machines.
>
> Single-purpose machines also have been much improved by numerical controls. For example, numericallly controlled boring machines have reduced downtime for loading and unloading by up to 30%. Numerical control applied to grinding machines often halves layout time; programmable electronic wheel feed and wheel retraction have been developed which reduce labor time and enhance precision. The design of hobs for gear cutting has been subjected to computer calculation, saving cutting time.
>
> [Duke and Brand, 1981, p. 31]

In addition to these considerations, CNC tools will increasingly be linked together, further reducing operator requirements per machine (ϕ^t). According to [American Machinist, 1981, p. 106], "Enhanced communication capabilities are also being incorporated in CNC systems, and one result of this is that these controls are, in effect, becoming terminals that can provide an interface between the operator and not only the individual machine tool but also the plant's overall computer hierarchy." Under Scenaro S2, we assume that average CNC labor requirements per tool are 80% of the conventional tool requirements in 1990 (ϕ^{90}) and fall to 50% under Scenario S3 by 2000 (ϕ^{2000}).

The ratio of the labor differential required per tool to the output differential per tool (ϕ^t/γ^t) gives the labor requirements per unit of output using CNC tools and β^t in Equation (14) (the labor savings per unit of ouput) is equal to $1-(\phi^t/\gamma)$.

The values of the parameters and the resulting coefficients are presented in Table 4.15. While the coefficients for all three occupations (LAB #30, 31, 46) were projected with the same method, the factors shown in row 4 of the table were applied to only the 75% of the Other Operatives (LAB #46) category who are machine operators. As a result, the impact of CNC tools on the labor coefficients for Other Operatives, shown in row 5, is lower than the impacts on Machinists (LAB #30) and Tool and Die Makers (LAB #31). Row 4 indicates that the labor requirements of these 2 occupations fall to 42% of their 1977 value by 2000 under Scenario S3.

Table 4.15. Impact of the Use of CNC Tools on Labor Coefficients (LAB #30, 31, and part of 46) in 1990 and 2000

	Scenario S2		Scenario S3	
	1990	2000	1990	2000
CNC Share of Machine Tool Stock in Units (α^t)	.06	.34	.23	.65
Ratio of CNC to Conventional Tool Labor Requirements per Tool (ϕ^t)	.80	.60	.70	.50
Ratio of CNC to Conventional Tool Output per Tool (γ)	4.50	4.50	4.50	4.50
Proportion of Labor Saved Through use of CNC Tools ($\beta^t=1-\phi^t/\gamma$)	.82	.87	.84	.89
Labor Coefficients for Machinists (LAB #30) and Tool and Die Makers (#31) as Proportion of 1977 Coefficient	.95	.70	.80	.42
Projected Labor Coefficients for Machine Operators (part of LAB #46) as a Proportion of 1977 Coefficient	.96	.77	.85	.56

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Chapter 5. The Automation of Office Operations

> The work processes of most offices are recognizable in industrial terms as continuous flow processes; they consist of the flow of documents to effect and record commercial transactions and contractual arrangements. While work processes are punctuated by personal interview and correspondence, these merely serve to facilitate the flow of documentation.
> [Braverman, 1974]

> Office automation [OA] incorporates appropriate technology to help people manage information. It is not a project with a defined point of completion nor is it the installation of a single functional element. Rather OA is the linking of multiple components or elements in such a way that information once entered can be processed from point to point with a maximum of technological assistance and a minimum of human intervention. [Frost and Sullivan, 1980a]

Electronic data processing during the 1950's and 1960's had a significant impact on large numbers of clerical workers, microprocessor-based office equipment of the 1970's extended the impact of electronic processing to a larger segment of white-collar workers, and integrated electronic information systems being put in place today affect virtually all white-collar workers. Section A of this chapter provides an introduction to recent developments in office technology which have important implications for capital, labor and intermediate input requirements. Section B briefly describes changes in the input requirements of firms that produce office equipment, and Section C describes detailed changes in the capital, intermediate and labor requirements of sectors that use electronic office equipment and integrated systems.

A. Introduction

Prior to the 1970's, the impact of the computer on office work was mainly to automate large routine and repetitive processing tasks. Separate data processing departments were created, in firms that could justify the purchase of a mainframe, to perform tasks already performed mechanically by clerical workers in the back office such as billing, payroll and certain bookeeping functions. The physical flow of information to and from the centralized data processing department often resulted in bottlenecks that limited the advantages of electronic processing. Thus, during the 1950's and 1960's, electronic computing technology had only minimal effects on office work. In many ways offices during this period resembled those of a hundred years earlier: pipelines that required a great many human pumping stations at regular intervals to see information, manipulate it, and transfer it to others [Braverman, 1974].

Advances in microelectronics during the 1970's reduced the cost and size of electronic processing and increased its application to office functions. Offices began to rely on electronic typewriters, word processors, optical character readers, and dictation equipment. These intelligent office machines have increased the productivity of secretaries, typists and other clerical workers previously unaffected by mainframe computer technology. More recently microprocessor technology has also reached managers and professionals in the form of desk top computers.

Until today the emphasis of microprocessor-based office technology has been to enhance the functional elements of office information systems already in place. Electronic or intelligent office machines have replaced conventional machines within the office and have improved the efficiency of the paper-based information system but these machines have not fundamentally altered the structure of the system. Information systems in the majority of offices are still based largely on paper as an interface medium and continue to require manual intervention. According to a reviewer of office technology at Fortune, "Not all terminals have been designed to communicate with big corporate computers; almost none can interact easily with work stations of another brand nor can they always do so with workstations of the same brand" [Uttal, 1982]. Microprocessor based office equipment saves labor time in many more office processing tasks than mainframe computers; however, since a major function of an office is not only to process but to communicate information, isolated intelligent equipment has had only limited impacts.

The major trend in office technology today is to replace the paper information system with electronic storage and transmission of information. In electronic office systems recently made available, each component performs its own computations including data and word processing and provides its own storage and communications interface. Separate components are linked together through high speed communications networks that allow users to share processing, access central storage facilities, and expedite the flow of information within an organization. Internal networks interconnect with common carrier networks to allow users on different local area networks to communicate. Integrated electronic information systems provide a vast application of computer and communication technology to office functions. As these systems become more versatile, they will enable organizations to capture information only once, and process, transfer, store and access the information at a later date with a minimum of human intervention. Thus, integrated systems with the potential to replace paper-based office systems may reduce the labor required to process information far beyond the savings introduced by intelligent machines that operate in isolation.

As it stands today integrated systems have been implemented only in establishments that employ large numbers of white collar workers such as large corporate offices. To adopt a fully integrated system requires significant start-up costs, and firms are hesitant to invest until they have a clear idea of their future processing and communication requirements. The average price of the complete systems installed for customers by Xerox, for example, is $270,000 [Uttal, 1982]. According to a study by the Rand Corporation, "Of the estimated 3.5 million offices in the U.S. about 1.5 million are currently large enough for some sort of advanced information system" [Bikson and Gutek, 1983]. This figure will increase as smaller and more flexible systems become available and start-up costs decline.

Falling hardware costs will continue to expand the potential use of new information systems. New storage technologies, for example, such as bubble and optical memories, provide tremendous storage capacities at a fraction of today's cost for electronic storage and will further enhance the advantage of electronic over paper based storage systems. Progress in microelectronics also results in a continuous increase in processing capacity and decline in its price. Some expect that 8K microprocessors capable of performing text editing will drop from $200 to $50 over the next ten years [Burns, 1980]. Others anticipate that

> individual chips will combine memory, logical processing, input-output interfaces, and, if appropriate, analog-to-digital conversion, allowing "intelligent" equipment functions to be dispersed to an unprecedented degree. [Spinrad, 1982]

Advances in communication technology will also play an important role in the move towards the automated office. Would-be purchasers of electronic office equipment are hesitant to invest now due to problems of compatability and a new awareness of the need for equipment with telecommunications capabilities. Networks that have the intelligence to allow previously noncompatible machines to interact will overcome these present deterrents.

Most intelligent networks available today are based on the ring principle that enables devices to communicate without going through a central network processor. Each device is connected to a local processor that injects messages from a message stream and monitors the stream for messages directed towards attached devices; the processor then extracts, formats and transfers them to the appropriate device. Since intelligence is distributed locally rather than relying on a central processor, networks based on the ring principle are faster, more reliable and more efficient than point to point or star networks. Although the ring-type systems are expensive at present, as memory and processing costs continue to fall and advances in fiber optics solve the need for large band widths, ring-type systems will offer great cost advantages to offices installing them over the next few years. According to [Spinrad, 1982], "Local communication networks using optical fibers are likely to become common toward the end of the decade."

Although vendors of office equipment are now selling local area networks, the Bell system and switchboard companies are also active participants in the local area network market with their automated PABX systems. PABX provides voice and data transmissions using digital technology over telephone networks which are already installed and connect to every desk. According to [Electronics Industry Association, 1982], 30,000 offices will have PBX equipment for audio, data and visual messages and for connecting interoffice work stations electronically by 1990.

Hardware components will continue to evolve rapidly, and software development will for some time be a major bottleneck to office automation. Analysts agree that most of the hardware components necessary to implement the electronic office are currently available [Spinrad, 1982; Frost and

Sullivan, 1980a]. In contrast, software programming for system hardware that automates the flow of information in offices will be the major development cost over the forseeable future. According to [Frost and Sullivan, 1980a], "Office systems on the market today are too complicated, too *ad hoc*, and do not meet informational requirements in a systematic way." The uncertain pace of software development may slow the diffusion of integrated office systems.

Firms can be expected to invest in office systems to expand output, to reduce unit costs, or to do both. A widespread perception today is that the salaries of managers, professionals and secretaries are rising while white-collar productivity is stagnant. According to one source, office salaries account for 50% of all business costs today [Mortensen, 1982]. This source also claims that office productivity rose by 4% between 1960 and 1970 while factory productivity grew by 80% over the same period. Low investment in office capital is the reason most commonly cited for this discrepancy. Several authors observe that while white-collar employees work with only $2,000 in equipment, a factory worker today is backed up by $25,000 in machinery [Byron, 1981; Uttal, 1982]. As the price of new office technology continues to fall dramatically, firms will move to replace labor intensive office information systems, and planned additions to capacity will rely increasingly on new office technologies.

Analysts agree that the market for integrated office systems is likely to be huge, but there is less consensus on when this market growth will occur. Frost and Sullivan see the market for office systems expanding rapidly over the latter part of the decade [Frost & Sullivan, 1980a]. Less optimistic analysts believe that the indirect costs of implementing office systems such as planning, training and supervision -- activities that can cost as much as the technology itself -- may inhibit investment in office systems [Uttal, 1982]. In many instances, in addition, new office procedures are not directly related to the production of a firm's principal output, and difficulty in measuring the productivity gains of new equipment is also seen as a deterrent to investment. Fortune cites a reviewer of office systems who finds office automation still poorly understood by business people:

> "Users can't articulate what they want and suppliers aren't that good at figuring it out . . .," says Patricia Seybold, the reviewer of office systems. "It's the blind leading the blind." So office automation will not arrive as a revolution, but gradually, as vendors and users educate each other. The journey to the promised land may not take 40 years but it is apt to remain painfully slow.
>
> [Uttal, 1982]

Since the pace at which the electronic office will begin to supplant the paper-based system is uncertain, it makes sense to consider two alternative scenarios. Scenario S2 assumes that firms will be slow to invest in integrated office systems and represents what now appears to be the lowest level of diffusion of integrated office technology that can be anticipated over the next 10 to 20 years. Scenario S3 represents, in our judgment, the maximum level of diffusion that is likely to occur through the year 2000. These scenarios will be described in more detail in the following sections.

B. The Production of Office Equipment

A shift in the composition of output produced by the Office Equipment sector, IEA #51, toward electronic text equipment will change its input requirements. In the early 1970's IEA #51 produced conventional office equipment such as typewriters, mail machines and scales and balances and duplicating machines. By the late 1970's, however, office equipment produced by this sector began to rely on electronic components: electronic mail machines, scales and balances, and electronic text equipment began to be produced in addition to conventional equipment. In the process, firms have necessarily increased their purchases of electronic components as reflected in the coefficient $a_{58,51}$ in the A matrix, i.e., the output of semiconductors, IEA #58, required to produce a unit of output of IEA #51.

We assume that all office equipment will be electronic by 1985. As a rough estimate of $a_{58,51}$ in 1985 we use the cost of a CPU board divided by the retail price of the word processor[1] and assume that this coefficient applies also to mail machines, scales and balances. The coefficient is interpolated for years between 1977 and 1985 and over this period represents a weighted average of the input requirements for conventional and electronic equipment. The value of $a_{58,51}$ rises from .004 in 1977 to .05 by 1985 and remains at this level through

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[1] Based on information provided by a technical supervisor at Hermes Business Products, Inc.

2000 under Scenarios S2 and S3. We assume that in all other ways the input structure of IEA #51 will remain unchanged after 1977.

C. The Use of Electronic Office Equipment

As offices within each sector of the economy invest in electronic office equipment and systems, other capital, intermediate and labor requirements will also be affected. A rise in the use of computers per unit of output, described in Chapter 4, will be the major change in capital requirements associated with the electronic office; however, demand for other office equipment will also be affected. Moreover, with increasing use of computers, demand for complementary inputs such as electricity and telecommunications and substitutes such as paper will be affected. The most important change, however, will be in the white-collar labor necessary to perform many job tasks. This section describes the methods, data and assumptions used to project changes in these technical coefficients with special emphasis on labor coefficients.

1. Capital Coefficients

The stock of office equipment, excluding office computers, per unit of sectoral output will increase through the mid 1980's but decline over the long run. Estimates of the annual market for electronic text equipment in the early 1980's range between two and seven billion dollars [Marchant, 1979; Uttal, 1982; Frost and Sullivan, 1980a; Electronics

Industries Association, 1982]. By the mid 1980's, however, analysts project that intelligent workstations (produced by the computer sector, IEA #50) with word processing facilities will take over the market for the electronic text equipment produced by IEA #51 [Frost and Sullivan, 1980a]. Conventional typewriters will also be replaced by electronic text equipment or intelligent work stations and faster, cheaper photocopy machines will make duplicating machines obsolete over the next few years.

Investment in office equipment is governed by two types of coefficients in the IEA model. The capital coefficient, b_{51j}, represents the office equipment required to expand the capacity of the j^{th} sector by one unit. There is also the "modernization" coefficient, r_{51j}, which describes purchases of new office equipment to replace obsolete equipment (or labor) in the absence of expansion. The remainder of this section describes the procedures used to estimate these coefficients.

To represent the combined effect of a temporary increase in the electronic text equipment and a decline in conventional office equipment required to expand output, we split the coefficients in row #51 of the B matrix into two parts as shown in Equation (1) and project the individual coefficients for 1977, 1985, 1990 and 2000:

$$b_{51j}=b_{\alpha j}+b_{cj} \qquad (1)$$

where

b_{51j} office equipment required to produce one additional unit of output of sector j in year t,

$b_{\alpha j}$ electronic text equipment required to produce one additional unit of output of sector j in year t, and

b_{cj} conventional office equipment required to produce one additional unit of output of sector j in year t.

We assume that the average new office put in place in 1977 used the same mix of technologies as the average office already in place. To estimate $b_{\alpha j}^{77}$, we first distribute the aggregate stock of electronic text equipment in 1977, $1.9 billion [Frost and Sullivan, 1980a], among sectors according to the percent of secretaries they employ. This distribution, shown in Table 5.1, allocates the largest stock to Business Services (IEA #77) and other service sectors such as Education, Wholesale and Retail Trade, Finance and Insurance. (Business Services includes the legal profession, which is said to derive the largest direct gain from word processors [Uttal, 1982].) This stock is then divided by the the sector's output in 1977 to produce the coefficients $b_{\alpha j}$.

As an estimate of b_{cj} in 1977 we use the coefficient b_{51j} for 1972, a year predating electronic office equipment. Thus we assume an increased use of office equipment per unit of output between 1972 and 1977 with the entire increase consisting of electronic text equipment.

The coefficients $b_{\alpha j}$ are projected based on growth in the aggregate stock of electronic text equipment per unit of gross output of the entire economy. This aggregate coefficient grew by 37% annually from 1976-1980 [Frost and Sullivan, 1980a; U.S. Department of Labor, 1982]. Under Scenario S2, we assume that this coefficient rises at an

Table 5.1. Sectoral Distribution of Secretaries in 1978

Code	Sector	Percentage
1	Livestock and Livestock Products	0.1%
2	Other Agricultural Products	0.1
3	Forestry and Fishery Products	0.1
4	Agricultural, Forestry, and Fishery Services	0.2
5	Iron and Ferroalloy Ores Mining	0.0
6	Nonferrous Metal Ores Mining	0.0
7	Coal Mining	0.0
8	Crude Petroleum and Natural Gas	0.6
9	Stone and Clay Mining and Quarrying	0.0
10	Chemical and Fertilizer Mineral Mining	0.0
11	Construction	2.6
12	Ordnance and Accessories	0.2
13	Food and Kindred Products	1.0
14	Tobacco Manufactures	0.0
15	Broad and Narrow Fabrics, Yarn and Thread Mills	0.3
16	Miscellaneous Textile Goods and Floor Coverings	0.1
17	Apparel	0.5
18	Miscellaneous Fabricated Textile Products	0.1
19	Lumber and Wood Products, except Containers	0.2
20	Wood Containers	0.0
21	Household Furniture	0.2
22	Other Furniture and Fixtures	0.1
23	Paper and Allied Products, except Containers	0.4
24	Paperboard Containers and Boxes	0.2
25	Printing and Publishing	1.8
26	Chemicals and Selected Chemical Products	0.5
27	Plastics and Synthetic Materials	0.2
28	Drugs, Cleaning and Toilet Preparations	0.6
29	Paints and Allied Products	0.1
30	Petroleum Refining and Allied Industries	0.3
31	Rubber and Miscellaneous Plastic Products	0.6
32	Leather Tanning and Finishing	0.0
33	Footwear and Other Leather Products	0.1
34	Glass and Glass Products	0.1
35	Stone and Clay Products	0.4
36	Primary Iron and Steel Manufacturing	0.4
37	Primary Nonferrous Metals Manufacturing	0.3
38	Metal Containers	0.1
39	Heating, Plumbing and Structural Metal Products	0.4
40	Screw Machine Products and Stampings	0.3

(continued on next page)

Table 5.1 (continued)

Code	Sector	Percentage
41	Other Fabricated Metal Products	0.4%
42	Engines and Turbines	0.1
43	Farm and Garden Machinery	0.1
44	Construction and Mining Machinery	0.2
45	Materials Handling Machinery and Equipment	0.1
46	Metalworking Machinery and Equipment	0.3
47	Special Industry Machinery and Equipment	0.2
48	General Industrial Machinery and Equipment	0.3
49	Miscellaneous Machinery, except Electrical	0.2
50	Electronic Computing Equipment	0.4
51	Office, Computing, and Accounting machines, except IEA #50	0.1
52	Service Industry Machines	0.3
53	Electric Industrial Equipment and Apparatus	0.5
54	Household Appliances	0.1
55	Electric Lighting and Wiring Equipment	0.2
56	Radio, TV, and Communications Equipment	0.7
57	Electron Tubes	0.1
58	Semiconductors and Related Devices	0.1
59	Electronic Components, nec	0.2
60	Miscellaneous Electrical Machinery and Supplies	0.2
61	Motor Vehicles and Equipment	0.6
62	Aircraft and Parts	0.6
63	Other Transportation Equipment	0.3
64	Scientific and Controlling Instruments	0.5
65	Optical, Ophthalmical, and Photographic Equipment	0.3
66	Miscellaneous Manufacturing	0.5
67	Transportation and Warehousing	2.0
68	Communications, except Radio and TV	1.2
69	Radio and TV Broadcasting	0.3
70	Electric, Gas, Water, and Sanitary Services	0.9
71	Wholesale Trade	7.5
72	Retail Trade	5.7
73	Finance	5.5
74	Insurance	6.5
75	Real Estate and Rental	2.1
76	Hotels, Personal and Repair Services except Auto	1.2
77	Business Services	15.1
78	Eating and Drinking Places	0.5
79	Automobile Repair Services	0.2
80	Amusements	0.8
81	Hospitals	5.0
82	Health Services, excluding Hospitals	5.4
83	Educational Services	11.6
84	Nonprofit Organizations	7.1
85	Government Enterprises	0.5
	Total	100.0

Source: [U.S. Department of Labor, 1980a].

annual rate of 45% until 1983 and falls to zero by 1985 by which time electronic text equipment is replaced by intelligent workstations. Under Scenario S3 we project a lower expansion in the requirements for electronic text equipment as users move more quickly to intelligent workstations. This scenario assumes a 35% annual increase in the aggregate coefficient until 1983 and a rapid fall to zero by 1985. Consequently $b_{\alpha j}^{77}$ increases by a factor of 9.3 (45% annual increase) by 1983 under Scenario S2 and by a factor of 6.1 (35% annual increase) under Scenario S3. We assume no change in the distribution of the stock of word processors across using sectors.

Coefficients regulating the future use of conventional equipment in new offices, b_{cj}, depend on several assumptions regarding the rate at which conventional machines are made obsolete. By 1985 under Scenario S2 we assume that investment in intelligent workstations will reduce the use of conventional typewriters (b_{cj}) by 75%, based on estimates of the market for typewriters [Electronic Industries Association, 1982], and that the requirements for duplicating machines will fall to zero. Typewriters and duplicating machines comprised 38% and 9%, respectively, of the capital goods portion of the output of IEA #51 in 1972 [U.S. Department of Commerce, 1980b]. We assume that these proportions also reflect the approximate share of these machines in the total stock requirement for office equipment and thus a 75% decline in the demand for typewriters and a complete phase-out duplicating machines reduces b_{cj} to 62% of its 1977 value by 1985 (Scenario S2). Under Scenario S3 we assume that electronic text equipment and intelligent workstations will completely replace conventional typewriters by 1985; the coefficient for conventional equipment is 53% of its 1977 value. There are no further reductions in these coefficients after 1985 under either scenario.

With respect to modernization in the absence of expansion (R matrix), electronic replaces conventional office equipment through 1985, and both are replaced by integrated office systems produced by the Computer sector (IEA #50) after 1985. We estimate the replacement coefficients by first calculating the yearly change in the projected stock of electronic text equipment required to produce a 1977 level of gross output in each year from 1977 to 1985 [Frost and Sullivan, 1980a; U.S. Department of Labor, 1982]. Since these projections are for a constant level of output, the yearly increment in this stock can be interpreted as total investment for modernization. As a second step, we allocate this total across sectors based on the percent of secretaries employed in each sector and divide by the output of that sector in 1977.

2. Intermediate Coefficients

As firms move toward the electronic office they will also change their demand for certain intermediate inputs. They will increase their requirements for network services supplied by the telecommunication sector and are also likely to increase requirements for electricity and reduce purchases of paper. Since integrated office systems are only now being put in place, the magnitude of such changes is unclear.

In this study we assume that intermediate coefficients for telecommunications, electricity and paper remain at the 1977 levels through 2000 for all scenarios.

3. Labor Coefficients

The magnitude of decline in labor coefficients for a particular occupation due to OA will depend on a variety of factors. Each occupation encompasses several tasks and changes in labor coefficients will depend on the amount of time that a worker spends performing a particular task and the amount of automatic equipment applied to that task. Another consideration is the amount of the office worker's time that can be saved in performing a particular task by the use of automatic equipment. "Listening" typewriters, for example, can save 100% of the time required to produce a typewritten document while electronic typewriters may save only 50% of typing time. Also pertinent is the percent of workers of a particular occupation and sector that actually use the new technology in a given year. Finally, an increase in demand for certain office activities may partially offset labor savings from new technology. Equation (2) shows how labor coefficients can be projected to take each of these factors into account:

$$l_{kj}^{t} = \sum_{f=1}^{F} w_{fkj}[\mu_{fkj}^{t}+(1-\mu_{fkj}^{t})(1-\gamma_{fkj}^{t})(1+\rho_{fkj}^{t})]l_{kj} \qquad (2)$$

where the variables are defined as follows:

l_{kj}^{t} number of workers of occupation k per unit of output of sector j in year t,

γ^t_{fkj}	proportion of time saved by the new technology relative to the old technology for workers of occupation k in sector j performing task f $(f=1,\ldots,F)$,
μ^t_{fkj}	proportion of workers in occuaption k in sector j performing task f in year t who are not affected by the new technology,
ρ^t_{fkj}	increase in demand for task f performed by workers of occupation k per unit of output of sector j in year t,
w_{fkj}	proportion of the time workers of occupation k in sector j spent in performing task f in the base year, just prior to the change in technology, where $\sum_{f=1}^{F} w_{fkj}=1.$
l_{kj}	number of workers of occupation k per unit of output of sector j in the base year, just prior to the change in technology.

Equation (2) adjusts a base year coefficient to reflect the diffusion of a time-saving technology and an increase in demand for certain labor functions. The expression $(1-\gamma^t_{fkj})(1+\rho^t_{fkj})l_{kj}$ shows the amount of time necessary to perform a particular task with the new equipment. To process 200% more text with a technology that saves 80% of the time required with the old technology, for example, requires 60% of the time that would have been required for the text-processing task with the old technology, $(1-.8)(1+2)=.6$. Clearly an increase in demand for text processing moderates the amount of time saved by the new technology.

The parameter μ_{fkj} preserves the old labor coefficient for workers of occupation k in sector j who do not work with a new technology that affects task f. If $\mu^t_{fkj}=.75$, i.e., only 25% of the workers of occupation k in sector j use word processors in the above example, then the labor required for text processing per unit of output of sector j in year t, as a proportion of the labor required in the base year, is .75+.25(.6)=.9.

The parameters w_{fkj} weight each task performed by its share of total labor time. If secretaries, for example, spend only 20% of their total labor time processing text and if office technology affects no other secretarial tasks then, continuing the example above, the new labor coefficient for secretaries would be .8(1)+.2(.9)=.98 l_{kj}.

In the absence of sufficiently detailed information on the breakdown of labor tasks we have simplified the parameters in Equation (2). For most occupations, we distinguish only between those tasks that can be automated and those that cannot, and the parameter w_{kj} represents the proportion of time of workers of occupation k in sector j spent on tasks that can be automated. The proportion of time saved by the automatic equipment on the average in affected tasks is γ_{kj}, and μ_{kj} represents the proportion of workers not affected by automatic equipment (all in year t). We also assume that $\rho_{fkj}=0$ for all tasks, occupations and sectors. Equation (2') incorporates these modifications of Equation (2):

$$l^t_{kj} = [w^t_{kj}(\mu^t_{kj}+(1-\mu^t_{kj})(1-\gamma^t_{kj}))+(1-w^t_{kj})]l_{kj} \qquad (2')$$

Table 5.2 contains the labor coefficients for each scenario as proportions of the coefficients in 1977, based on Equation (2'). Since the IEA occupational classification is in some cases more aggregated than the detail in which these computations were

Table 5.2. Labor Coefficients in 1990 and 2000 as Proportions of Labor Coefficients in 1977

	Scenarios S2		Scenario S3	
	1990	2000	1990	2000
Managers (LAB #17) all sectors except IEA #76, 78, 79, 80	.99	.88	.84	.50
Sales Workers (LAB #18) sectors IEA #72, 78, 79, 80	.98	.96	.94	.89
all other sectors	.99	.95	.84	.75
Stenographers, Typists and Secretaries (LAB #19)	.85	.76	.65	.45
Office Machine Operators (LAB #20)	.45	.15	.28	0.00
Bank Tellers (LAB #21)	.80	.60	.60	.36
Telephone Operators (LAB #22)	.88	.81	.63	.50
Cashiers (LAB #23)	.98	.95	.93	.85
Other Clerical Workers (LAB #24)	.88	.74	.68	.59

Note: All entries computed with Equation (2') except the fourth row (LAB #19) which was computed with Equation (2).

carried out, for certain occupations (LAB #19, 20, 24), the proprotions in Table 5.2 are weighted averages of the proportions for more detailed occupations. These proportions apply to all IEA sectors except where noted, assuming that tasks performed by white-collar workers in a particular occupation are relatively homogeneous across industries and that new office technology is used by the same share of workers in an occupation for all industries.

The remainder of this section describes the information and assumptions that underlie the parameters used to calculate the proportions in Table 5.2. The discussion is organized by occupation, and the parameters for each of eight occupational categories (LAB #17-24) are summarized in Tables 5.3-10. Where possible, parameter values are based on the findings of case studies of the direct impact of office technology on particular occupations. Future studies will hopefully provide more systematic and detailed information on these parameters.

Managers (LAB #17)

> The advent of desk top computers and other information tools linked together by advanced telecommunication networks that provide access to widely diverse sources of data heralds a huge surge in productivity for approximately 10 million managers in the U.S. [Business Week, 1983b]

> For office automation to realize its promise, the manufacturers must reach beyond the secretary to managers and professionals who account for 80% of white collar salaries. [Uttal, 1982]

Desktop computers integrated into networks can save a significant amount of time that managers spend processing information. With direct access to external and internal data banks, managers can prepare market studies, forecast competition and develop pricing strategies in a few hours -- activities that once took several months of work. Moreover, keyboard access to electronic files can reduce the amount of time spent looking for information, and graphics software enables managers to digest information quickly from computer printouts.

In addition to providing managers with local processing power, integrated systems can save time in a variety of communication activities. Electronic mail can expedite dissemination of memos within an organization and correspondence between firms. Systems that record telephone messages digitally (by computer) and forward them to others within a company can reduce time spent trying to make contact with others. Computerized scheduling of meetings avoids the need for contacting other managers individually, and teleconferencing can eliminate much of the travel time associated with meetings in different locations.

Beyond the time saved in managerial activities, integrated systems may also eliminate certain middle manager positions entirely. According to [Business Week, 1983b], the role of middle managers since World War II has been to collect, analyze and interpret information and pass it on to executives. "As more top managers see that much of the information once gathered by middle managers can be obtained faster, less expensively and more thoroughly by computers, they have begun to view many middle managers as 'redundant.'" Specialized software programs that can replace certain middle management tasks include computerized inventory control, production scheduling, and allocation planning for limited resources. In addition as integrated office systems reduce the number of clerical and other white collar workers, fewer managers will be needed to supervise them.

The parameters used to project the coefficients to 1990 and 2000 are shown in Table 5.3. The Electronic Industries Association estimates that 3% of all managers and professionals used desk top computers in 1982, and International Data Corporation (IDC) estimates that this share will rise to 65% by 1990 [Electronic Industries Association, 1982]. For Scenario S2 we assume that 10% of all managers in each industry will use desk top computers or managerial work stations by 1990 (μ_{17j}=.90). By 2000 we assume that this share will be at least 50%. For Scenario S3 we use the IDC estimate that 65% of managers will use work stations by 1990. By 2000, we assume that all managers use work stations under these scenarios.

The values of the parameter w_{17j}, the percent of a manager's time spent in tasks that can be automated, are based on a survey of managerial and professional productivity by management consultants Booz Allen and Hamilton. They found that middle managers on average spend 52% of total work time at meetings, 12% creating documents, and 16% analyzing and reading. The 20% of work hours that remain are spent in activities such as waiting for meetings, organizing information, expediting and assigning tasks as well as scheduling, searching for information,

Table 5.3. Parameters that Determine Labor Coefficients for Managers (LAB #17) in 1990 and 2000

	Scenario S2		Scenario S3	
Parameters	1990	2000	1990	2000
All sectors except IEA #76, 78 79, 80				
Proportion of Managers not affected by new technology (μ_{17j})	.90	.50	.35	0.00
Proportion of Managers' time spent in tasks affected by new office technology (w_{17j})	.15	.25	.25	.50
Proportion of Managers' time saved by new technology relative to old (γ_{17j})	1.00	1.00	1.00	1.00

Note: Inserting these parameters in Equation (2') results in the proportions in the first row of Table 5.2.

filing, copying, transcribing and other clerical-type activities. The study concludes that 15% of a manager's time can be saved by electronic office systems over the next five years [Business Week, 1983a]. Based on these findings, for Scenario S2 we assume that by 1990 managers with executive work stations can save 100% of their labor time (γ=1.00) in the 15% of their labor tasks that are mainly clerical (w=.15). As specialized managerial software is designed for integrated systems under Scenario S3, we assume that 25% of all managerial activities may be fully automated by 1990, and at least this amount will be automated by 2000 even under Scenario S2. By 2000 we assume that integrated systems may fully automate 50% of managerial activities under Scenario S3.

Changes to the labor coefficients for managers apply to all sectors except Hotels (IEA #76), Eating and Drinking Places (IEA #78), Automobile Repair (IEA #79) and Amusements (IEA #80). A large share of the managers in these retail sectors are proprietors or managers of single-manager establishments on whom office technology will have a negligible effect.

Sales Workers (LAB #18)

The sales staff in most sectors seeks out clients, travels, provides potential buyers with information, and processes paperwork. By contrast, in retail establishments, which employ over 50% of all sales workers, the job requires no travel, limited sales promotion and much more time processing a greater volume of transactions. Since electronic office technology will have a different effect on these two categories of sales workers, labor coefficients were projected separately.

The effects of automation on labor requirements for sales workers in retail establishments will be similar to that for cashiers. While sales persons in retail stores generally interact with customers more than cashiers, most of their time is devoted to processing transactions. Electronic technology in retail sales work reduces the time required to process transactions and record inventory information at check-out points. Point-of-sales terminals can raise productivity of sales clerks by 10% according to [Maeda, 1981]. Another study of the impact of automated checkout equipment on cashiers notes a similar gain; labor requirements to process the same volume of transactions were reduced between 10% and 15% [U.S. Department of Labor, 1979b].

The parameters used to project the coefficients for retail sales workers, shown in Table 5.4, are based on these studies and other assumptions. Under Scenario S2, we assume that point of sales terminals save 10% of the time required to process transactions and record inventory information with conventional cash registers. For Scenario S3 we assume that this equipment may save as much as 15% of this time.

In addition, for Scenario S2 we assume that only 25% of sales workers will use point-of-sales terminals by 1990 but that this share will rise to 50% by 2000. Under Scenario S3 we further assume that 50% of all retail sales workers may use automated checkout equipment by 1990 and that all sales workers may be affected by the year 2000. These are the same parameters used below for cashiers, and since retail sales workers have other tasks besides processing and recording transactions, we assume that unlike cashiers only 75% of a sales worker's time is affected by automated equipment. The 25% of a sales worker's work time that remains is spent assisting customers and keeping store merchandise in order, activities that will be unaffected by electronic technology.

While electronic technology will affect only the transaction processing task of sales workers in retail establishments, sales workers in most industries will be affected in a variety of ways. Direct access to computerized external data banks

Table 5.4. Parameters that Determine Labor Coefficients for Sales Workers (LAB #18) in 1990 and 2000

	Scenario S2		Scenario S3	
Parameters	1990	2000	1990	2000
Retail Sectors (IEA #72, 78, 79, 80)				
Proportion of Sales Workers not affected by new office technology (μ_{18j})	.75	.50	.50	0.00
Proportion of Sales Worker time spent in tasks affected by new office technology (w_{18j})	.75	.75	.75	.75
Proportion of time saved by new technology relative to old (γ_{18j})	.10	.10	.15	.15
All Other Sectors				
Proportion of Sales Workers not affected by new office technology (μ_{18j})	.90	.50	.35	0.00
Proportion of Sales Workers time spent in tasks affected by new office technology (w_{18j})	.50	.50	.50	.50
Proportion of time saved by new technology relative to old (γ_{18j})	.20	.20	.50	.50

Note: Inserting these parameters in Equation (2') results in the proportions in rows 2 and 3 of Table 5.2.

from government and private sources will assist sales people in identifying markets. Mobile telephones, voice message systems and portable terminals will provide ready access to cost estimates, product supply, and delivery dates while also minimizing visits to field offices. Moreover, portable terminals will make it possible to process transactions more quickly.

Parameter projections for nonretail sales workers are shown in the bottom portion of Table 5.4. Each scenario assumes that 50% of a sales worker's time will be affected by office automation. This ratio, higher than that for managers and lower than that for secretaries, is based on the assumption that nonretail sales workers spend at least half their work time in face-to-face interaction with customers. The amount of time saved by the technology in those tasks that are affected is based on an estimate by vendors that sales persons can reduce selling time by 50% when they use office computer facilities and communication networks [Business Week, 1983a]. We use this estimate for Scenario S3 and for Scenario S2 we assume that office systems will save at least 20% of the time spent in affected tasks. Finally, we assume that the share of nonretail sales workers that use automated systems in a given year is the same as that reported for managers.

Secretaries, Typists and Stenographers (LAB #19)

As a communications intermediary among managers, professionals, and others both inside and outside an organization, a secretary performs a variety of tasks that are affected by electronic office technology. At present, office technology has had its greatest impact on typing. Studies show that approximately 500,000 or 11% of all secretaries used word processing equipment in 1981 [Walsh, 1982]. This equipment produces remarkable gains in productivity when it is properly selected and used. According to one study,

> typical individual secretaries ostensibly type 60 words per minute. Actually, when all the error white-outs and page-length remakes are figured in, they only type three or four words per minute. Typing specialists with automated equipment and good supervision can achieve from 15 to 30 words per minute, again taking into account all the setting up, referencing, and button-pushing. This represents a speed-up of from 500 to 1,000 percent.
> [Administrative Management, 1978]

Several studies show that the time saved by word processing equipment can reduce labor requirements up to 50%. One review of a large multi-service law firm notes reductions of 50% in the number of typists required per constant dollar of revenue [Murphree, 1982]. Another study cites several cases where word processor installations have reduced office staffs by one third to one half [Dowing, 1980]. In one research organization word processing equipment reduced average number of days to prepare a report by 20%, effectively reducing the labor requirement by 20% [Karon, 1982].

While an increase in demand by firms for processed text will offset a decline in labor requirements, this effect will, in most cases, be temporary. One study of a word processing installation notes that a common occurrence with word processors is that a lot of hidden work appears that has never been done before due to a lack of secretarial support [EDP Analyzer, 1980]. A properly managed word processing installation, however, will allow only those increases in typed material that add directly or indirectly to the total output of the firm. Thus, although employment may not change as word processors are installed, labor requirements per unit of output will still fall as output rises.

Although word processing will continue to provide significant gains in the productivity of typists, voice input technology will completely automate the typing task. Computer based interpretation of voice data is an extension of dictation systems that bypasses the transcription task of secretaries. According to researchers at the IBM research center,

> with a listening typewriter, an author could dictate a letter, memo or report. What he or she says would be automatically recognized and displayed in front of him or her. A listening typewriter would combine the best features of dictating (rapid human output) and the best features of writing (visual record/easy editing). No human typist would be required and no delay would occur between the time an author creates a letter and when he or she gets it back in typed form.
> [Gould, Cort and Horanyecz, 1982]

Although several voice data entry products are presently available for single-word application such as inventory, quality control and credit authorization, according to researchers at IBM, "machine recognition of speech uttered by any person may or may not be achieved early in the next century" [Gould, Cort and Horanyecz, 1982]. Listening typewriters being tested today have a limited ability to discern word segmentation in normal speech patterns. When voice input technology does become available for every day office use, virtually all white collar workers will be affected. This application, however, is still in the development stage, and we make no attempt to incorporate its impacts on labor requirements. Rather we consider only the continued diffusion of word processing facilities in the form first of stand-alone equipment and then of integrated work stations.

Word processing facilities will have their greatest impact on secretaries who type full time, approximately 22% of the workers in LAB #19 [U.S. Department of Labor, 1981]. We assume that 100% of a typist's time will be affected by word processing that saves 80% of the time required with conventional typewriters. This represents a 500% increase in productivity, the lower bound on the productivity increase of word processing cited above [Administrative Management, 1978]. Furthermore, we project that at least 40% (Scenario S2) but as many as 70% (Scenario S3) of all typists will use word processing facilities by 1990. These estimates are based on the fact that 11% of all secretaries used word processing equipment in 1980 [Uttal, 1982] and the expectation that the real price of text-editing equipment will continue to fall over the 1980's. By 2000 we assume that at least 70% (Scenario S2) of all typists will have word processing facilities, and under Scenario S3 we assume that all typists will use them. These parameters are shown under section b of Table 5.5.

Table 5.5. Parameters that Determine Labor Coefficients for Secretaries and Typists in 1990 and 2000

	Scenario S2		Scenario S3	
Parameters	1990	2000	1990	2000
a. Secretaries				
Proportion of Secretaries not affected by word processing ($\mu_{1,19a,j}$)	.60	.30	.30	0.00
Proportion of Secretary time spent in tasks affected by word processing ($w_{1,19a,j}$)	.20	.20	.20	.20
Proportion of time saved by word processing relative to conventional typing ($\gamma_{1,19a,j}$)	.80	.80	.80	.80
Proportion of Secretaries affected by other office technology ($\mu_{2,19a,j}$)	.90	.50	.35	0.00
Proportion of Secretary time affected by other office technology ($w_{2,19a,j}$)	.45	.45	.45	.45
Proportion of time saved by new technology relative to old ($\gamma_{2,19a,j}$)	.25	.25	.75	.75
b. Typists				
Proportion of Typists not affected by word processing ($\mu_{19b,j}$)	.60	.30	.30	0.00
Proportion of Typist time spent in tasks affected by ($w_{19b,j}$)	1.00	1.00	1.00	1.00
Proportion of time saved by word processing ($\gamma_{19b,j}$)	.80	.80	.80	.80

Note: Taking a weighted average of the two proportions defined by inserting the parameters for a into Equation (2) and the parameters for b into Equation (2') results in the proportions in row 4 of Table 5.2. As weights we use secretaries and typists as a share of LAB #19 in 1978 as reported in [U.S. Department of Labor, 1981].

Word processing facilities will have much more moderate effects on secretaries who spend only part of their time typing. Secretaries not classified as full-time typists comprise 76% of all workers in LAB #19 [U.S. Department of Labor, 1981]. For them, we use the same parameters as for full-time typists except for the weight of the typing task in total secretary work time. Studies show that on average secretaries spend approximately 20% of total work time typing [Green, 1982; Walsh, 1982].

Although word processing will affect only a small share of secretaries' work time, integrated office systems will affect many other secretarial tasks depending upon the facilities available at manager and professional work stations. At the limit, a manager who can access information from an electronic file, dictate a memo into a desk top computer, edit it verbally, and distribute and file it electronically will require little secretarial assistance. For these reasons, we assume that if a certain proportion of managers is connected to a network in year t, the network will extend to the same proportion of secretaries in that year.

Nonetheless, the share of secretarial time affected by office automation will be significantly greater than that of managers at least for the near future. Secretaries spend approximately 45% of their work time filing, mailing, making photocopies, delivering messages and waiting for work [Green, 1982]. Offices with secretarial workstations connected to electronic filing cabinets, electronic mail systems and local printers will save time in all these areas. In each scenario we assume that 45% of all secretarial time will be affected by office automation other than electronic text processing.

The proportion of time saved will depend on the share of offices and office workers connected to the network. As long as some offices or clients are not connected electronically to others, inter-office communication will require that secretaries handle paperwork. Even when all offices are completely automated, however, these tasks will still consume at least some secretarial time. We assume that office systems will save at least 25% of the time spent in affected activities (Scenario S2) and that this equipment may save as much as 75% of this time (Scenario S3).

Microprocessor based office technology will continue to replace full-time stenographers who now comprise about 2% of LAB #19 and whose work will be completely automated by 1990. Stenography has been a declining occupation since the 1960's when IBM first marketed its magnetic belt dictation unit. In addition to desktop and portable units available today, central dictation systems based on microprocessor technology serve many users, require fewer dictation units and can be accessed over the telephones. One study shows that 60-70% of all organizations have some form of dictation equipment but that only one third of all people who originate typewritten work today use dictation machines [Frost and Sullivan, 1982]. As offices continue to increase efficiency, utilization of dictation equipment will increase. Each scenario assumes that stenographers are completely replaced by 1990.

Office Machine Operators (LAB #20)

Office Machine Operators include clerical workers who operate conventional office equipment such as tabulating, calculating, bookkeeping, billing, keypunch machines and those who operate peripheral computer equipment. Operators of conventional equipment represented 66% of all office machine operators in 1970; by 1978 this share dropped to 44%. An increase in the number of workers who operate peripheral computer equipment over the 1970's more than compensated for the decline in operators of conventional equipment, and the total number of operators grew by over 30% between 1970 and 1978 [U.S. Department of Labor, 1981].

Computer technology will soon eliminate all operators of conventional office machines including keypunch operators. Small businesses that can now afford computers will replace conventional equipment, and data typists using video display terminals will continue to replace keypunch operators over the short run. We assume that the labor coefficient for operators of conventional equipment will fall to zero by 1990 in both scenarios.

The labor coefficient for operators of peripheral equipment such as data typists will fall less dramatically over the next two decades. As firms attempt to raise office productivity by increasing the amount of information captured electronically they will invest in automated equipment such as optical readers (OCR's) and electronic cash registers that record information at the point of transactions. OCR's (machines that transfer information into digital bits of computer language) can read 75-120 characters per second while a fast keyboard operator can achieve at best 7. Until now, OCR's have been used mainly to read utility payments and charge card slips, and to scan the 80% of first class mail that is typewritten [Brody, 1983]. Recent advances which have made OCR's much more reliable and reduced the cost to approximately $7,000 dollars will accelerate the replacement of data typists.

The labor coefficient for other types of peripheral computer operators will also decline in the future. As distributed electronic processing replaces mainframe installations, workers who load and change tapes and remove output from high speed printers at these facilities will also be displaced. We assume that mainframe attendants and data typists can be completely eliminated. Under Scenario S2, 20% of these workers will be displaced by 1990 and 80% by 2000. Scenario S3 accelerates this displacement to 50% by 1990 and 100% by 2000. These assumptions are summarized in Table 5.6.

Bank Tellers (LAB #21)

> A human teller can handle up to 200 transactions a day, works 30 hours a week, gets a salary anywhere from $8,000 to 20,000 a year plus fringe benefits, gets coffee breaks, a vacation and sick time. . . . In contrast, an automated teller can handle 2000 transactions a day, works 168 hours a week, costs about $22,000 a year to run and does not take coffee breaks or vacations. [Bennett, 1983]

Table 5.6. Parameters that Determine Labor Coefficients for Office Machine Operators in 1990 and 2000

	Scenario S2		Scenario S3	
Parameters	1990	2000	1990	2000
Operators of Peripheral Computer Equipment				
Proportion of Operators not affected by new office technology ($\mu_{20a,j}$)	.80	.15	.50	0.00
Proportion of Operator time spent in tasks affected by new office technology ($w_{20a,j}$)	1.00	1.00	1.00	1.00
Proportion of time saved by new technology relative to old ($\gamma_{20a,j}$)	1.00	1.00	1.00	1.00

Note: Inserting these parameters in Equation (2') and multiplying by the share of LAB #20 whc operate peripheral computer equipment as reported in [U.S. Department of Labor, 1981.] results in proportions in row 5 of Table 5.2.

Automated transaction machines (ATM's), having achieved widespread acceptance by the American public, will have significant impacts on the labor requirements for human bank tellers. According to a report by economists at the BLS, the effectiveness of these machines in reducing waiting lines and extending banking hours allowed banks to install 1900 ATM's by 1980 [Brand and Duke, 1982]. Moreover, the average number of transactions per month on ATM's grew by 250% from 1976 to 1980. One bank reports that two ATM's can perform the work of three human tellers [Bank Systems and Equipment, 1983]. According to [Brand and Duke, 1982], larger banks can more easily justify the purchase of ATM's, while for many small and medium-sized banks, the relatively high fixed costs of equipment are not offset by the savings in labor costs at current volumes of business -- a factor that tends to retard the diffusion of the devices.

Future labor coefficients for bank tellers depend on several assumptions. Based on discussion with an official in the transactions processing department of Citicorp Bank, we assume that 80% of the transactions that bank tellers perform are routine and can therefore be performed by ATM's. We further assume that by 1990 at least half (Scenario S2) but perhaps all (Scenario S3) large banks will install ATM's. Large banks with assets in excess of $500 million employ almost 50% of all bank employees [Frost and Sullivan, 1980b]. If large banks employ the same share of bank tellers, then at least 25% (Scenario S2) but as many as 50% (Scenario S3) of bank tellers will be affected by 1990. By 2000, at least all large banks will install ATM's (Scenario S2) while under Scenario S3 all medium sized banks will follow suit. Since medium banks, with assets between $50 and 500 million, employ 31% of all bank employees, we assume that 80% of all bank tellers may use ATM's by 2000 (Scenario S3). Table 5.7 summarizes these assumptions.

Table 5.7. Parameters that Determine Labor Coefficients for Bank Tellers in 1990 and 2000

	Scenario S2		Scenario S3	
Parameters	1990	2000	1990	2000
Proportion of Bank Tellers not affected by automation ($\mu_{21,73}$)	.75	.50	.50	.20
Proportion of Bank Teller time spent in tasks affected by automation ($w_{21,73}$)	.80	.80	.80	.80
Proportion of time saved by new technology relative to old ($\gamma_{21,73}$)	1.00	1.00	1.00	1.00

Note: Inserting these parameters in Equation (2') results in coefficients in row 6 of Table 5.2.

Telephone Operators (LAB #22)

Continuous advance in the technology for switching telephones and recording information has steadily reduced the number of operators required to support a given number of telephones. In 1910, the Bell system employed 100,000 operators to service seven million telephones. By 1970, the system provided services to 98 million telephones with only 166,000 telephone operators [Scott, 1982]. Several technological innovations account for this remarkable gain in productivity. The development of cross bar switches in the 1940's increased network capacity and in part made possible the introduction of direct distance dialing in 1951 that greatly reduced the number of operator-assisted calls. More recently computers have been used to automate equipment through stored program control. Electronic switching systems (ESS), for example, use stored program control to switch telephone calls. Although EES has its greatest impact on installers and maintenance workers, it is also changing many of the duties of operators through electronic consoles that automate most of the switching and billing tasks on operator-assisted long distance calls. In 1979 almost 75% of all telephones were serviced by these consoles which are reported to increase operator efficiency by 25% [U.S. Department of Labor, 1979b]. Other computer based applications that will automate certain types of operator tasks are computer assembled voice intercept devices and systems that automate coin telephones.

Future labor requirements for operators will depend on the rate at which computer applications become available to certain types of telephone operators. Since the telecommunication sector is likely to remain a rapid innovator we assume that at least 50% (Scenario S2) but as many as 75% (Scenario S3) of the operators will be affected by 1990. By 2000 we assume that at least 75% (Scenario S2) but perhaps all operators (Scenario S3) will be affected by new computer software. In both scenarios, computer applications are assumed to affect 100% of an operator's tasks. As an estimate of the time that computers save in operators' tasks under Scenario

S2, we use the 25% efficiency gain of electronic consoles cited by the Department of Labor. Under Scenario S3, we assume that this parameter may be as large as 50%. These parameters are shown in Table 5.8.

Table 5.8. Parameters that Determine Labor Coefficients for Telephone Operators in 1990 and 2000

	Scenario S2		Scenario S3	
Parameters	1990	2000	1990	2000
Proportion of Operators not affected by automation (μ_{22j})	.50	.25	.25	0.00
Proportion of Operator time spent in tasks affected by automation (w_{22j})	1.00	1.00	1.00	1.00
Proportion of time saved by new technology relative to Old (γ_{22j})	.25	.25	.50	.50

Note: Inserting these parameters into Equation (2') results in proportions in row 7 of Table 5.2.

Cashiers (IEA #23)

Cashiers, the third largest clerical occupation after secretaries and bookkeepers, accounted for almost one and a half million workers or 1.5% of the entire labor force in 1978. This was almost 50% greater than total employment of cashiers in 1970. The majority of cashiers, 62%, are employed in Retail Trade, 18% are employed in Eating and Drinking Places, and the remaining cashiers are scattered throughout the economy [U.S. Department of Labor, 1981].

The diffusion of computerized checkout systems will have a significant impact on cashiers. The most common type of computerized checkout machines today are supermarket scanners which transmit the universal product code of each purchase to a computer that is programmed to record the description and price of an item, add the tax, and print out a receipt. According to one study of 38 supermarkets in the Washington area that installed scanner equipment, "a fully scanner equipped supermarket was found to have a 5% lower labor requirement than an unautomated store with the same volume" [Gilchrist and Shenkin, 1982]. Another survey cited by the BLS finds that "an electronic front end permits a 30% increase in operator ringing speed and a possible overall 10 to 15% reduction in unit labor requirements for cashiers and baggers" [U.S. Department of Labor, 1979b].

In addition to supermarket scanners, other forms of electronic checkout equipment will save the time of cashiers in nonfood retail stores. Point-of-sales terminals that read magnetically encoded vendor market merchandise tickets save data entry time of cashiers in large department, apparel and discount stores. Moreover, electronic cash registers that perform credit card authorization tasks further reduce the unit labor requirement for cashiers.

We assume that 100% of a cashier's work time will be affected by automated checkout equipment. Based on the study cited by BLS, we further assume that automated equipment saves 10% of the checkout time required for a given volume of transactions under Scenario S2 and for Scenario S3 that this equipment may save 15% of a cashier's time. Since all large food stores are expected to install scanner equipment by 1990 [Gilchrist and and Shenkin, 1979] and large supermarkets employ about 10% of all cashiers in the Retail Trade sector [U.S. Department of Commerce, 1980a], we estimate that at least 25% of all cashiers (Scenario S2) will use automated equipment by 1990 assuming full automation of large supermarkets and department stores. By 2000 we expect that at least 50% of cashiers will use automated equipment. For Scenario S3 we assume that at least 50% of all cashiers will use automated equipment by 1990 and that all check-out stations will be electronic by 2000. Tabe 5.9 summarizes these assumptions.

Table 5.9. Parameters that Determine Labor Coefficients for Cashiers in 1990 and 2000

	Scenario S2		Scenario S3	
Parameters	1990	2000	1990	2000
Proportion of Cashiers not affected by new technology (μ_{23j})	.75	.50	.50	0.00
Proportion of Cashier time spent in tasks affected by new technology (w_{23j})	1.00	1.00	1.00	1.00
Proportion of time saved by new technology relative to old (γ_{23j})	.10	.10	.15	.15

Note: Inserting these parameters into Equation (2') results in proportions in row 8 of Table 5.2.

Other Clerical Workers (IEA #24)

The remaining 50% of clerical workers not discussed above are classified in a variety of clerical occupations that can be divided into two groups based on the potential effects of office automation.

Clerical workers who manipulate data and have little or no interaction with the public will continue to feel a greater impact than any other group of white collar workers. Although mainframe computers have been able to perform the tasks of back-office clerical workers, such as bookkeepers, file, billing, payroll, and statistical clerks since the 1960's, computer technology could not affect the multitude of clerical workers in small offices until recently. Small business computers and electronic cash registers that perform a variety of bookkeeping and inventory functions will reduce the need for these workers. Moreover, as electronic processing becomes more widely distributed, clerical workers in remote locations can also be affected. New microprocessor based-time clocks, for example, calculate overtime hours and vacation days accrued and perform a variety of other data manipulations previously performed by payroll clerks. The latest models of these machines interface with computers that process paychecks, eliminating the need for payroll clerks [High Technology, 1983]. As another example, office purchasing systems that automate the control of office supplies can reduce the need for stockroom labor. At one company a purchasing system permits one person in the stock room to handle the needs of 400 offices in 2-4 hours a week rather than the 60 hours it previously took 1 1/2 persons [*Administrative Management*, 1981]. In short, any function previously performed by clerical workers in this group can be performed faster and more efficiently by some microprocessor--based office machine that gets cheaper every year. It is safe to say that these clerical occupations will soon be completely automated. We assume in Scenario S2 that at least 25% of these clerical jobs will be automated by 1990 and 50% by 2000. Under Scenario S3 we assume that the jobs of 65% of these clerical workers could be fully automated by 1990 and by 2000 automation may affect 100% of the clerical workers in this group.

The majority of other clerical workers, however, perform activities that are more difficult to automate since they require interaction with the public; these include bill collectors, counter clerks, dispatchers, interviewers, real estate appraisers, and receptionists. Although most of these jobs will not be eliminated, computer technology will save time in carrying out certain clerical tasks by providing faster access to information.

Under both scenarios, we assume that office systems by 1990 will save 50% of the labor time in 25% of the job tasks of clerical workers who interact with the public. By 2000 we assume that office systems will save time in half these activities. The share of these clerical workers affected by office technology in any year is the same as that for clerical workers who manipulate data. Table 5.10 summarizes these assumptions.

Table 5.10. Parameters that Determine Labor Coefficients for Other Clerical Workers in 1990 and 2000

	Scenario S2		Scenario S3	
Parameters	1990	2000	1990	2000
a. Clerical Workers Who Manipulate Data				
Proportion of Clerical Workers affected by automation ($\mu_{24a,j}$)	.75	.50	.35	0.00
Proportion of Clerical Worker time spent in tasks affected by automation ($w_{24a,j}$)	1.00	1.00	1.00	1.00
Proportion of time saved by new technology relative to old ($\gamma_{24a,j}$)	1.00	1.00	1.00	1.00
b. Clerical Workers who Interface with Public				
Proportion of Clerical Workers affected by automation ($\mu_{24b,j}$)	.75	.50	.35	0.00
Proportion of Clerical time spent in tasks affected by automation ($w_{24b,j}$)	.25	.50	.25	.50
Proportion of time saved by new technology relative to old ($\gamma_{24b,j}$)	.50	.50	.50	.50

Note: Taking a weighted average of the two proportions defined by inserting the parameters for a and b into Equation (2) results in the proportions in row 9 of Table 5.2. As weights we use Clerical Workers in a and b as a share of LAB #24 in 1978 as reported in [U.S. Department of Labor, 1981].

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Chapter 6. Education

A. Introduction

The progressive automation of both the production and consumption of goods and services in our economy is placing new demands on our educational system. The increasing use of computers and related devices in office work and manufacturing requires an increasingly technologically literate workforce. Certain industries, like the computer industry itself, are dependent on creative innovations in fields where knowledge changes rapidly. For this reason, continuing education is required by many professionals to remain current and productive in their disciplines and in some cases for renewal of their licenses. Conventional education is also affected, and in a school system which must adapt to the new requirements teachers will need additional training. Personal computer manufacturers already provide simple educational packages in response to household demand which can be expected to grow considerably in the future to supplement traditional forms of education and to provide formal or informal job training or recreation.

It has traditionally been assumed that education is for the young, work is for early and mid-adulthood, and old age is the time for neither. While the location, the hours of instruction and the structure of educational programs reflect this assumption, increasing numbers of students and potential students do not fit that pattern. Another attribute of conventional education is its method of instruction, typically a one-way flow of information from teacher to student in a classroom. Two relatively new forms of education based on presently available technologies, Computer-based Instruction (CBI) and Instructional Television (ITV), provide electronic courseware, which is well-suited to both the lifelong learning concept and the development of new ways of learning.

The purpose of this chapter is to describe quantitatively as well as qualitatively how economy-wide technological change may affect education. We examine both conventional education and new technologies and describe ways in which our educational system may be transformed by the use of electronic courseware. Electronic courseware is discussed in Section B, and the input structures for conventional education and electronic courseware are described in Section C. The new forms of education will be used by three major groups -- industry, conventional education, and households -- and section D describes three alternative scenarios about the use of electronic courseware up to the year 2000.

One function of education is training, which can be expected to help make possible the future reductions in labor coefficients assumed in other chapters of this report. The formulation of scenarios describing education and training for workers other than professionals -- especially clerical and production workers -- and the use of electronic courseware (and computers generally) in the home are areas requiring further study.

B. The Technology of Education

Our present educational system has been experiencing an increased dropout rate and declining average daily attendance, increased numbers of students performing below grade level, and declining scores on various tests. Seventy-five percent of firms in one survey provided their employees with internal training programs in basic skills which were apparently not learned in school. AT&T, for example, spends $6 million annually to train about 14,000 employees in basic reading and math skills [Center for Public Resources, 1982]. Another survey found that 35% of corporations had provided some high school level training for their employees, and the skill levels of those not hired may be even lower.

It has been argued that education is a mature industry and further investment in existing educational technologies will not significantly improve its quality or alleviate its problems. Indeed, as the society undergoes basic changes, education will also have to change in order to continue to provide the training necessary for its members to function productively in society.

Conventional educational technology utilized chalk and blackboard, books, maps and wall charts; the media were print and speech. Technological change in education has expanded the tools used for learning from mostly written, teacher-mediated and controlled techniques to include the use of video presentation and computers with the potential for fostering a more active participation by the student.

The most dramatic developments in education are occurring in interactive technologies, mainly computer-based instruction, where the learner determines the speed and sequence of the program, and video-based instruction which can free the student from the time and place constraints of conventional education. While these forms of electronic courseware affect both the content and the delivery of education, this study concentrates on their impacts on educational delivery.

Computer-based Instruction (CBI) requires both software and hardware which consist of the computer itself, access terminals, and either a television or a teleprinter with a keyset. Early systems required a large computer, either on the premises or through telecommunication links. The smaller, inexpensive, independent microcomputers which have recently become available are already estimated to outnumber terminals attached to large computers by 3 to 2 in educational applications [U.S. Department of Education, 1982]. The software consists of a computer language for interaction and the courseware itself (pre-packaged lessons).

First developed in the 1950's to train computer industry personnel, CBI entered schools on an experimental basis in the 1960's. Programmed Logic for Automated Teaching Operations (PLATO) was the first major system, developed in the 1960's at the University of Illinois with support from Control Data Corporation and the National Science Foundation. Microcomputers, actively marketed on a national level only since 1978, have given new impetus to the use of computers in schools by making significant computational capability and flexibility accessible at an affordable price.

More schools, however, use computers for records, bookkeeping and other administrative tasks than for educational purposes. In the 18 months between fall 1980 and spring 1982, personal computers for educational purposes in schools increased from 31,000 to 96,000 (over 100% annually), while all computer terminals grew about 14% during the same period [Melmed, 1982b]. Computers in schools are expected to reach 980,000 by 1986 [Geller, 1983], growing at an annual rate between 1982 and 1986 of 46%. About 35% of all public schools now make at least one computer terminal or microcomputer available to students, the majority in secondary schools. In 1981-82 $28.5 million was spent on educational software, estimated to grow to $120 million in 1985.

Despite the breakthrough in hardware, results to date in schools using CBI have been mixed, due to inadequate teacher training and low quality courseware. Programs have typically emphasized the choice and financing of hardware, with software and teacher training viewed as secondary.

Computers were introduced into some French secondary schools in an experimental program from 1970-1976 [Hebenstreit, 1980]. Over this period, six hundred teachers received full-time training at the end of which each teacher developed a courseware package. (Science and mathematics teachers were deliberately kept in the minority). An additional 5,000 teachers were trained in applications of computers in the classroom, with specialized workshops and conferences. More than 500 high quality courseware packages were written, and over 7,000 copies of these packages are now in use. The program is considered to be very successful, and its success is attributed to the identification of the crucial role of the teachers. Of the total budget, 70% went to teacher training and release-time; only 30% was spent on hardware. The underlying assumption of that French program was that better quality courseware could be developed by teachers given some computer training than by computer specialists with some help from teachers.

In the U.S. most observers assume that the schools will buy courseware from private firms analogous to textbook companies [Melmed, 1982b]. The high cost and limited quality of available software, due in part to the fact that the courseware is written mainly by computer specialists and not teachers, keeps the demand from growing rapidly, thus dampening the incentive of the private sector to commit additional resources. As the industry matures such difficulties will be overcome, but a major initiative on the part of schools will be required before a large market for software can develop. While the general orientation is toward the purchase of courseware, a large number of schools do create their own. One recent study found that 20% used locally produced software and 55% used a combination [Harvard University Graduate School of Education, 1982]. In addition, two major computer companies, Tandy and IBM, recently proposed extensive teacher training programs.

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The use of computers in education has been classified into three categories -- tool, tutor and tutee [Taylor, 1981]. The computer as tool functions merely as a powerful calculator. As tutor, CBI can be used in drill and practice, essentially a reproduction on the computer of exercise workbooks presently used in schools. Simulation is a more sophisticated version stressing applications of what has been learned. This mode provides more personal attention for the individual student but is essentially an extension of conventional learning procedures. The computer must be programmed by experts and provided with expensive courseware.

In the tutee mode, students teach the computer and in the process they learn about the subject, the computer, and how they themselves think. The need for expensive courseware is presumably reduced since students learn to program the computer themselves; education becomes the use and understanding of information, not memorization of facts. An example of this mode is the Logo system developed by Seymour Pappert and his colleagues. The computer as tutee is still viewed as experimental and requires an exceptional teacher but is bound to become increasingly important.

Currently the most extensively used form of CBI is computer assisted instruction (CAI) which falls under the tutor mode. Schools now consider computer literacy the top priority of CBI, followed by presenting a challenge to high achievers and enriching the learning experience [U.S. Department of Education, 1982]. Fewer than half report using CBI for remedial purposes or drill and practice, although drill and practice does dominate in elementary schools, the level with the least computer use [Instructor, 1982].

Video-based instruction, mainly Instructional Television (ITV), is the other major component of electronic courseware. An early example is Sunrise Semester, an ambitious general adult education program which began in the late 1950's and recently ended broadcast due to low station membership.

The Appalachian Community Service Network broadcasts more than 64 hours a week with over 1.1 million subscribers, providing both 1-way and 2-way education and teleconferencing service. The University of Idaho Video Outreach Program expects household viewers to reach 41,000 by 1990, about 5% of the state's population [Grayson and Biedenbach, 1982], and the University of Pennsylvania recently announced plans to initiate a similar program. These programs respond to a specific need of industry, professionals or the local community, define relatively narrow goals, and emphasize the quality of the product. The prime target for educational programs has been graduate level education for scientists, engineers and managers, as a part of formal on-the-job training programs.

Video-based instruction degree programs in the scientific and management disciplines began on a local basis in the late 1960's. Typically the instructor presents the material to a regular, on-campus class but in a modified classroom which allows simultaneous live broadcast with or without talkback or taping for cassettes. Those viewing the class by television may be tutored by a special assistant on the job, a senior engineer at the firm, or through periodic visits by the instructor.

What originated as a response to professional and industry needs by individual universities such as MIT, Stanford and Colorado State is evolving into a consortium of universities organized on a profession-wide basis. One such effort is the Association for Media-Based Continuing Education for Engineers (AMCEE) whose 22 member universities have contributed 450 courses on cassettes and account for over 85% of all off-campus ITV in engineering. Of about one million working engineers in 1980, 44,000 or 4.4% were enrolled in graduate degree programs via ITV at their places of work [Baldwin and Down, 1981]. The majority were under 35 with only a B.S. degree, indicating a new educational trend among younger workers.

The education system is very decentralized, almost a cottage industry, resistant to change on a large scale. In the early days, computerized instruction was often motivated by a desire to increase productivity in education; automating education was supposed to be cost-effective [Baldwin and Down, 1981]. At this point the cost of producing a video cassette of a class is much less than the cost of good quality CBI courseware and, more important, CBI has not yet been successfully integrated into the overall educational experience.

As acceptance grows and production technology matures, CBI will come into much wider use; however, it will never completely replace ITV. Video presentation will have an important role whenever talkback participation, dramatization, and demonstrations are required. To teach scientists new experimental techniques a demonstration is necessary, and the training of health workers often relies on techniques or documentation of subjects which requires the use of video. The American Bar Association found video indispensable for certain kinds of training and established the Consortium for Professional Education in 1975, to teach such things as courtroom techniques and jury selection, which require dramatization [Grayson and Biedenbach, 1982]. The video presentation is also an important way for more people to experience particularly charismatic teachers.

As the industry develops, there will be much greater use of combined video and computer-based learning, particularly video disc technology which combines the student-paced, interactive learning of CBI with the visual presentation of graphics or documentation necessary for many subjects. The visual presentation may also enliven educational packages, making the subject more interesting and tangible to the student and improving both the quality and the range of subjects suitable for CBI.

It may become increasingly difficult for the technologically illiterate or unsophisticated to function in the future. Both the kind of jobs available and the scope of social life in which they can participate will be severely restricted. Legislation is before Congress now to provide tax credits for computer purchases to households and schools, and a national policy about computer literacy and public education will need to be formulated.

C. The Production of Education, 1963-2000

Four separate educational sectors have been represented for this study: public and private conventional education (IEA #89, 83) and two sectors producing electronic courseware (IEA #87, 88). The corresponding input structures are described in this section.

1. Conventional Education

Conventional IO tables treat public and private education differently although they deliver roughly the same output with similar input structures. Private education is a producing sector within the technical matrices and delivers its output to actual users, mainly households. Public education is represented as part of government final demand. This treatment is the outcome of early debates about the appropriate representation of nonmarket activities in the national accounting framework [Gilbert, et.al., 1948].

We have moved public education inside the matrices as a separate education sector (IEA #89). To accomplish this for the years 1963-1977 required distinguishing capital investment from allocation to current inputs because capital purchases for public education, as part of government final demand, were combined with current account. Capital purchases for past years were estimated based on the purchases of private education (from the CFT's), and the remaining flows were divided by total output (discussed below) and moved into the A matrix. Columns for other matrices were assumed to be the same as for private education. The entire output of the sector is absorbed by households.

The other change from the official data regards the measure of educational output. Education has no physical product identifiable as its output (like other "service" sectors), and in the official accounts the value of its output is defined as the sum of its input costs. The official price deflator, in turn, is based on the changing cost of labor inputs. These conventions produce rather arbitrary measures of change in real output.

Since the principal activity of schools is to educate students, we redefined the measure of one unit of educational output as a student-year of education; total enrollment was weighted to reflect the costs of educating students at different levels in terms of equivalent primary school students. (In the future, the BEA will disaggregate education by level in the IO tables.)

The Department of Education estimates that the cost per secondary school student is 50% higher than the cost per primary school student, so the former receives a weight of 1.5. While higher education costs per student can vary considerably, they have been on the average about 2.5 times the cost per primary school student. We have used this weight with two part-time students considered equivalent to one full-time student. Table 6.1 shows numbers of students

Table 6.1. Output of Education (IEA #83, 89), 1963-2000
(thousands of students)

Year	Elementary	Secondary	Higher Education	Total	Adjusted Total[a]	Adjusted Total Public Education[a]	Adjusted Total Private Education[a]
1963	34,504	12,120	4,234	51,908	61,667	49,345	12,322
1967	36,752	13,790	6,401	56,943	70,912	57,503	13,409
1972	34,953	15,377	9,215	59,545	78,506	64,016	14,490
1980	31,619	15,300	11,600	58,519	76,679	64,501	12,178
1985	31,500	13,700	11,350	56,550	75,479	63,263	12,216
1990	35,000	12,100	11,100	58,200	76,030	63,576	12,454
2000	37,200	14,900	11,100[b]	63,200	82,036	69,018	13,018

[a] Equivalent in terms of primary school student-years. See explanation in text.

[b] The National Center for Education Statistics does not have an estimate for higher education in 2000, but expects enrollment to increase in the mid-1990's the 18-25 year old group increases. The 1990 estimate is a lower limit for 2000.

Sources: [Frankel, 1981; Frankel and Gerald, 1982, Grant and Eiden, 1980] enrolled and their equivalent in terms of primary school student-years. A change of unit (from dollars' worth to students) was performed for the public and private educational sectors in the technical matrices for 1963-1977. For future years, the totals shown in Table 6.1 were interpreted as projected demand.

For 1963-1977 the input structures for the public and private education sectors used in the IEA model are as given in the official data, adjusted in the ways described above. For future years this structure is maintained with additional purchases of electronic courseware, to be described in the following section, resulting in increased cost per student.

Over the period covered by the historical data, per student real costs have been increasing for labor, intermediate and capital inputs. While the public sector dominates eduction, with 88% of total enrollment and expenditures in 1972 of $64 billion compared to $12 in the private sector, the trends in cost per student have been similar for public and private education.

There is, however, a persistent gap between the level of public and private costs, the latter usually higher. For all levels the trend has been toward increasing enrollment per public school, especially in higher education, while in private schools the average number of students increased slowly if at all [Grant and Eiden, 1980]. The difference in higher education enrollment also contributes to the cost gap: higher education accounted for 30% of total private enrollment by 1972 with only a quarter as many students per school.

One factor contributing to the overall increase in costs is the changing product mix. Between 1963 and 1972, the share of secondary school students remained fairly constant for both public and private schooling but elementary school enrollment declined from 69% to 60% in pubic education and from 64% to 51% in private while higher education's share has risen from 6% to 13% and from 20% to 30% in public and private schools, respectively.

Labor cost is the single largest input to education, and its share of total expenditures has risen since 1963 in the private sector and declined somewhat in the public sector. Most important intermediate inputs are the same for both public and private education: Business Services, Eating and Drinking Places, Utilities, Transportation and Warehousing, and Maintenance and Repair. The four major manufactured inputs are Printing and Publishing, Paper and Allied Products, Miscellaneous Manufactures (mainly athletic goods, pens, pencils, art supplies and marking devices), Chemicals and Drugs, and Petroleum and Plastic Products (in which the main entries are cleaning supplies, paints, motor vehicle lubricants and gas). Real Estate is a large intermediate input.

2. Electronic Courseware

Some CBI courseware is currently produced by independent firms, including producers of personal computers, and some is produced by individual users of computers. Much of the existing electronic courseware consists of ITV tapes and broadcasts of regular classes, generally produced in affiliation with institutions of higher education.

Electronic courseware was not combined with the two existing education sectors because both the input structures and outputs differ and may be "consumed" independently. Instead the IEA sectoral classification is expanded to include CBI (IEA #87) and ITV (#88), bringing the total number of education sectors to four. Following the literature, we measure CBI output in 1-hour packages and ITV output in thirty-hour courses.

The data presented in this chapter are based on studies of ITV which provide a detailed input structure in physical units and costs [Morris, 1974]. Courses may be taped or broadcast live and an average of the two was assumed. The SURGE program at Colorado State University provided the taped course input structure and Stanford's Instructional Television, the live broadcast. Table 6.2 shows the technical coefficients for ITV at the present time. This input structure is assumed to remain unchanged through the year 2000. (Costs are measured on a per viewer basis, and ITV output represents the total number of viewers taking a 30-hour course without regard to how many distinct courses are viewed.)

Table 6.2. Input Coefficients For ITV (IEA #87), 1980 to 2000 (1979 dollars of input per 30 hour course)

Code	Sector	Interindustry Coefficients	Capital Coefficients
22	Other Furniture and Fixtures	0.1777	3.3515
23	Paper and Allied Products	3.3327	----
25	Printing and Publishing	1.5506	----
51	Office Equipment	0.1454	2.4309
53	Electric Industrial Equipment	0.1858	6.7192
55	Electric Lighting and Wiring	3.3677	
56	Radio and TV Equipment	0.9852	18.7606
57	Electron Tubes	0.1131	2.1805
59	Electronic Components, nec.	0.1454	2.6893
64	Scientific and Controlling Instruments	0.0727	1.4133
65	Optical, Ophthalmic and Photographic Equipment	0.0242	0.4684
67	Transportation and Warehousing	8.3425	----
68	Communications, except Radio and TV	1.6152	---- ----
77	Business Services	15.5060	----
85	Government Enterprises	1.5506	----

Code	Occupation	Labor Coefficients (workers per 30-hour course)
17	Managers, Officials, Proprietors	.0003
16	Other Professional and Technical Workers (TV Technicians and Engineers)	.0011
19	Stenographers, Typists, Secretaries	.0007
25-28	Maintenance and Construction Workers	.0006
52	Laborers	.0014
14	Teachers	.0014

CBI output represents the total number of one-hour courses developed, independent of the number of copies or individual users. The school system is the major user of CBI, and it is assumed that it makes its own additional copies as copies as required.

A one-hour CBI package is estimated to cost $30,000 in 1980 dollars for direct technical inputs, mostly the labor of teachers and computer programmers. An additional $90,000 per package is required for overhead including support services, management, marketing and profit, which we represent as a purchase from Business Services, IEA #77. Under Scenario S3 which assumes a greatly expanded market, overhead per unit of output can be expected to fall. (See Section D below for the description of Scenarios S3'.) The rest of the input structure is assumed to remain unchanged. Technical coefficients for CBI are shown in Table 6.3.

D. The Use of ITV and CBI: 1980, 1990, and 2000

1. Industry Use of Electronic Courseware

Certain producing sectors of the economy have made formal, on the job training an integral part of their research and development efforts. We expect to see the greatest future use of electronic courseware in the following sectors:

Electronic Computing and Related Equipment
Communications
Radio, TV and Communications Equipment
Aircraft and Parts
Scientific and Controlling Instruments
Chemicals (Biogenetics)
Business Services: (Business Management, Computer Programming, and Commercial Research and Development)
Finance
Insurance
Health

Table 6.3. Input Coefficients for CBI (IEA #88)
under Scenarios S2, S3, and S3' in 2000
(1979 dollars of input per 1 hour course)

Interindustry Coefficients		Scenario		
		S2	S3	S3'
Code	Sector			
23	Paper and Allied Products	$ 200	$ 200	$ 200
77	Business Services	90,000	30,000	90,000
Capital Coefficients				
Code	Sector			
50	Electronic Computing Equipment	8,000	8,000	8,000
56	Radio, TV and Communications Equipment	800	800	800
Labor Coefficients		(workers per 1-hour course)		
Code	Occupation			
6	Computer Programmers	0.5	0.5	0.5
14	Teachers	0.5	0.5	0.5

Scientists and engineers in industry will pursue "continuing education" both because knowledge is changing rapidly in their specialities and because the number who complete a graduate education is declining -- presumably because high starting salaries are offered to those with a B.S. while support for graduate study is low. In addition, many professors are leaving the universities for higher-paying jobs in industry, reducing the capacity for producing scientists and engineers in the future.

Surveys indicate that time is the most serious obstacle to continuing education while working, particularly travel time and the inflexibility of class scheduling [Grayson and Biedenbach, 1982]. Electronic courseware offers a solution to these interrelated problems since it can be administered in the workplace, alleviating the scheduling constraints and making specialized classes and a small number of outstanding educators available to many people. Assignments can be done with the company's laboratory equipment and computers which are often more up-to-date than that found on campus. Mainly ITV, and very little CBI, has been used in this type of technical training, and our scenarios assume that this trend will continue.

In 1980, 4.4% of working engineers participated in degree programs via ITV, taking a minimum of one course per year. We assume that a similar rate (0.04 ITV courses per employee) applies to scientists. (This does not include additional courses beyond the minimum degree requirements or any courses viewed in nondegree training programs.)

To determine the use of ITV by scientists and engineers in specific sectors, we made use of the percentages of those personnel receiving all types of formal on-the-job training, according to a study prepared for the Office of Technology Assessment [Cooke, 1982]. These are shown in Table 6.4. The industry-wide average shown in this table is 18%, about four times that for ITV alone (4.4%), so we assume that use of ITV in 1980 is one-quarter of the rates shown in Table 6.4. ITV is expected to experience rapid growth, and the percentages reported in Table 6.4 for 1972-73 for all formal training are assumed under Scenario S2 to hold for ITV alone by the year 2000. Each user of ITV is assumed to take one 30-hour course per year.

Table 6.4 also shows other sectors, not included in the OTA study, which are expected to use ITV for formal training of scientists and engineers in the future: the reported rates were based on other sectors.

Table 6.4. Scientists and Engineers Receiving Formal On-the-Job Training in 1972-73 (percentages)

Industry	
Ordnance and Accessories	31.2%[a]
Chemicals and Selected Chemical Products	22.2
Fabricated Metal Products	15.3
Machinery except Electrical	18.6
Electronic Computers & Office Machinery	46.3
Electrical Machinery	30.1
Electronic Apparatus	28.0
Aircraft and Parts	25.4
Motor Vehicles and Equipment	31.2
Industry-Wide Average	18.0
Communications	34.8%[b]
Instruments	30.4
Business Services	
Commerical R & D	15.2
Business Management	15.2
Computer Programming	15.2

[a] This group of sectors from [Cooke, 1982].
[b] Following sectors are IEA estimates.

Industrial use of ITV courses in 2000 is quantified for alternative scenarios in Tables 6.5 and 6.6. The numbers reported for Scenario S2 in Table 6.5 are taken directly from Table 6.4 with the exception of Business Services. The subsectors of Business Services indentified in Table 6.4 are assumed to account for about half the scientists and engineers employed in the sector as a whole, yielding the coefficient of .076 30-hour ITV courses shown for that sector in Table 6.5.

Under Scenario S3, employees in the dominant engineering or scientific occupation in a given industry can be expected to receive one unit of ITV in addition to usage by other scientists and engineers assumed under Scenario S2. For example the usage rate for electronic engineers in the computer industry will be 1.00 and the rate for all other engineers and scientists will be 0.463. These numbers are shown in the last column of Table 6.5.

Electronic courseware has also been usd to train managers: the MBA program is currently a major part of ITV offerings and is growing rapidly. Many states have begun to impose educational requirements for license renewal especially for lawyers, accountants, architects and various health professionals. The American Hospital Video Network, for example, is developing a program to provide continuing education and medical news to all hospitals in the U.S.

Rates of ITV use in 2000 by workers other than scientists and engineers are shown in Table 6.6: in all cases this use is assumed to be twice as intensive under Scenario S3 (and S3') under Scenario S2. The industry-wide average use of .18

Table 6.5. Use of ITV (IEA #87) by Scientists and Engineers (LAB #1-8) in 2000 (30-hour courses for Scientist and Engineer)

Code	Sector	Scenario S2	Additional Use Under Scenario S3 for Selected Occupations
12	Ordnance and Accessories	.312	
26	Chemicals and Selected Chemical Products	.222	1.00 Natural Scientists (LAB #5) .50 Other Engineers (LAB #4)
39-41	Fabricated Metals	.153	----------
42-49, 52	Machinery	.186	----------
50-51	Computers and Office Machinery	.463	1.00 Electrical Engineers (LAB #1)
53-55, 57-60	Electric machinery	.301	1.00 Electrical Engineers
56	Radio, TV, and Communcations Equipment	.280	1.00 Electrical Engineers
61	Motor vehicles	.312	----------
62	Aircraft	.254	1.00 Other Engineers
64	Scientific and controlling instruments	.304	1.00 Electrical, Industrial, Mechanical Engineers (LAB #1,2,3)
68	Communications (except 69)	.348	1.00 Electrical Engineers
69	Radio and TV broadcasting	.348	1.00 Electrical Engineers
77	Business services	.076	1.00 Electrical, Industrial, Mechanical Engineers

Note: Scientists and Engineers are included in LAB #1-8.

Table 6.6. Use of ITV by Other Workers in 2000
(30-hour ITV courses per worker)

Sector		Managers (LAB #17) S2	Managers (LAB #17) S3	Other Workers	S2	S3,S3'
12	Ordnance and Accessories					
26	Chemicals and Selected Chemical Products	.045	.090			
50-51	Computers and Office Machinery	.045	.090			
53-55, 57-60	Electric Machinery	.045	.090			
62	Aircraft	.045	.090			
64	Scientific and Controlling Instruments	.045	.090			
68, 69	Communications	.045	.090			
73, 74	Finance and Insurance	.045	.090			
77	Business Services	.0113	.023	Other Professional Technical Workers (LAB #16)	.050	.100
81	Hospitals	.0113	.0223	Health Professionals (LAB #10-13)	.125	.250
82	Health Services excluding Hospitals				.031	.063

courses per worker under Scenario S3 is assumed for high and middle-level managers who comprise about half the IEA managerial classification for LAB #17, yielding a coefficient of .090 for all sectors except Business Services and Hospitals. In these two sectors, managers eligible for ITV-based training comprise one-eighth the IEA classification, yielding a coefficient of .023.

Health and various other professionals will provide a large market for ITV products, but these will be slower to develop than the scientist, engineer and manager markets [Grayson and Biedenbach, 1982]. These professionals, especially those in service industries, require specialized training, often for license renewal, rather than standardized degree programs which can be taped from a conventional, college-based class. Health care institutions are small, decentralized and independent and tend to arrange their own training programs internally.

Lawyers, accountants and architects were estimated to account for 80% of the occupational category Other Professional and Technical Workers employed by the Business Services sector. Under Scenario S2 it is assumed that one-quarter of these professionals, or 20% of Other Professional and Technical Workers, obtain additional training; and 25% of these, or 5%, use ITV by 2000. This rate is doubled under Scenario S3.

Hospitals have always provided a disproportionately large amount of training because thier extensive, centralized facilities, often affiliated with a medical school, are well equipped for this purpose. Under Scenario S2, 12.5% of all health professionals employed by hospitals but only 3.1% of those in other health services, use ITV. The latter assumption is based on existing or proposed education requirements for license renewal for these professionals. Again, these rates are doubled under Scenario S3.

Under all scenarios the use of ITV is assumed to begin in 1980 at one-quarter the rates shown for Scenario S2 in 2000 (for an industry-wide rate of 4.5%) and to increase linearly, reaching the full value in 2000, except for Hospitals and Other Health Services. These two industries begin to use ITV in 1990 under Scenario S2, and in 1985 under Scenario S3 in an amount equal to one-tenth the value shown for Scenario S2 in 2000.

The information given in Tables 6.5 and 6.6 is assembled to produce row #87 of the A matrix for a given year, showing the distribution of ITV to using sectors, in the following way. The parameters describing the use of ITV per worker by occupation (i) for each industry (j), k_{ij}, are arranged in a matrix of 54 rows and 89 columns--exactly the form of the L matrix of labor requirements per unit of output, l_{ij}. The element-by-element product of these two matrices ($k_{ij}l_{ij}$) results in a matrix containing ITV requirements per unit of output by occupation and industry. The column sums, which represent total ITV input per unit of sectoral output, become row #87 of the A matrix.

2. Use of Electronic Courseware by the Public and Private Conventional Education Sectors

ITV in higher education is used essentially for off-campus students and is represented in this study as purchases by industry and households. CBI packages in higher education have been developed by instructors for their own use, and there has been little if any systematic distribution of such courseware at the university level. This section concentrates on the use of electronic courseware at the elementary and secondary level, where ITV will be used for teacher training and CBI for student instruction. The extent of usage will depend upon the availability of computers and prevailing attitudes toward their use in education.

Under Scenario S2 we assume that the use of computers in primary and secondary education grows slowly, reaching 980,000 personal computers by 1990[1] and 1,500,000 by 2000: this would provide one terminal for every thirty students by 2000, roughly one hour a week on the computer per student. Under this scenario the computers are used essentially in the tutor mode with purchased courseware and no use of ITV for teacher training. By 2000 only one CBI course per 5000 computers will be developed, and this with no savings relative to present cost structures.

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[1] This number is projected for 1986 by [Geller, 1983].

Under Scenario S3, electronic courseware is integrated into primary and secondary school curricula. A plausible national plan, outlined by Melmed [1982a] would provide enough hardware to give each student 1/2 hour a day on the computer. With 40 million elementary and secondary school students projected for 1990 and a 5-hour school day, about 4 million computers would be required. Adding another million for backup, this reaches a total of 5 million. Assuming an average 1982 cost of $1,000 per computer and a 5-year lifetime, Melmed estimates a $1 billion annual cost, or $25 per student, for hardware, a very small percentage of total educational costs. Under this scenario computer use continues to grow to about 10 million computers in the schools by 2000. Ten percent of all teachers receive training through ITV by 2000.

Scenario S3' also assumes a rapid growth in this form of education but with the initiative taken mainly by households rather than schools. Nonetheless, there will be twice as many computers in schools as under Scenario S2, for a total of 3,000,000 by 2000. High schools provide the basic skills required in the workplace such as computer literacy and word-processing and also use electronic courseware in mathematics and science classes. The rate of courseware use is the same as under Scenario S2; and while some teacher training is required, ITV is not used for this purpose.

Purchases of CBI and ITV are easily obtained using the parameters summarized in Table 6.7.

Table 6.7: Use of ITV and CBI by the Public and Private Education Sectors under Scenarios S2, S3, and S3' in 2000

Scenario	ITV per Teacher (30-hour course)	Computers per Student	CBI Courses per Computer (1-hour package)
S2	-	1/30	1/500
S3	1/10	1/5	1/750
S3'	-	1/15	1/500

3. Use of Electronic Courseware by Households

At present almost every household in the U.S. has at least one television set. Twenty-eight million residences were wired for cable by early 1982, and the number will reach 58 million by 1990 [Grayson and Biedenbach, 1982]. A large and growing number have personal computers as well, but there is relatively little use of electronic courseware by households at this time. Continuing education is growing in popularity, but it is unclear what share of this market will take the form of electronic courseware used in the home.

Children and adults, individually or in small group tutorials, could use electronic courseware for an enormous range of purposes including job-training and retraining programs, informal reading and general education, and the popular "continuing education" programs. Education based in the home could grow very rapidly indeed in light of what some consider a failure of traditional education.

For many workers general academic skills may be more important than the specific vocational training on which high schools have traditionally focused. The word processor, for example, is used more effectively by someone with the basic skills to handle and process information than by an excellent rote typist [Center for Public Resources, 1982]. The self-paced, individualized instruction made possible by electronic courseware is particularly important for remedial education where learners may be embarrassed and frustrated in conventional learning structures. Control Data Corporation has developed a CBI package for remedial education which has been successfully used by industry.

Under Scenario S2 we assume that the use of ITV in the home, which started in 1980 at a level of 9,000 courses, reaches only 200,000 by 2000, involving limited use for job retraining and mainly professional and general education for the highly educated and affluent and, notably, their children. Twice this amount of usage in 2000 is assumed under Scenario S3 (and S3'). In all cases this usage starts from the same low level in 1980 and grows linearly to 2000.

Under all scenarios we assume that the use of CBI by households begins at near zero levels (10 courses in 1980), grows relatively slowly between 1980 and 1990, and then more rapidly in the next decade. The technology of CBI is less familiar and accessible to most people than that of ITV, so we expect an initially slower growth of usage. Scenario S3 corresponds to the most intensive household usage, compensating for the slow adoption in primary and secondary schools. The total use of ITV and CBI is greatest under Scenario S4 since its use in the schools can be expected to promote professional and recreational use at home. CBI is not directly linked to computer use by households (as it is for education) since household computers will be used for games, business, financial and assorted other purposes. The assumptions about the use of electronic courseware by households are summarized in Table 6.8.

Table 6.8: Use of ITV and CBI by Households under Scenarios S2 and S3 in 1990 and 2000

Scenario	ITV in 2000 (30-hour courses)	CBI in 1990 (1-hour packages)	CBI in 2000 (1 hour packages)
S2	200,000	100	1000
S3	400,000	450	4500
S3'	400,000	600	6000

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Chapter 7. Health Care

A. Introduction

The health care system is an increasingly important sector in the national economy. It grew from 5.3% of GNP in 1960 to almost 10% in 1981, by which time it directly employed more than seven and a half million people. The provision of health care has undergone considerable change in organization, services provided, and input requirements for delivering these services. Current debates focus on issues of cost and the determination of what constitutes adequate health care.

Through the first half of this century the health care system was based on the independent practitioner. However, the delivery of health care has now decisively shifted toward hospitals because of the availability of new technologies requiring specialized personnel and equipment accompanied by the growth of third-party financing.

Health insurance originated in the 1930's to protect individuals requiring hospitalization from personal bankruptcy. By 1950, almost half of hospital costs were covered by third-party payments, mostly private insurance, and by the mid-1970's coverage had risen to 90% [U.S. Department of Health and Human Services, 1982]. Third-party coverage for total health care expenditures since 1929 is shown in Table 7.1. Until recently, health insurance paid fixed premiums and covered hospital care only; even today most insurance is for hospital care. This policy may encourage unnecessary hospitalization even for routine procedures and an excessive number

Table 7.1. Third Party Coverage of Health Care Expenditures, 1929-1980

Year	Percentage of GNP	Percentage Covered by Direct Payment	Percentage Covered by Third Party Payments		
			Total	Private	Public
1929	3.5	88.4	11.6	2.6	9.0
1940	4.0	81.3	18.7	2.6	16.1
1950	4.4	65.5	34.5	12.1	22.4
1960	5.3	54.9	45.1	23.3	21.8
1965	6.0	51.7	48.3	26.7	21.6
1970	7.5	39.9	60.1	25.6	34.5
1980	9.4	32.4	67.6	28.0	39.6

Source: [U.S. Department of Health and Human Services, 1982]

of tests and procedures per patient. In addition it may reduce the incentive for hospitals to contain costs, in turn allowing supplying industries (e.g., the pharmaceutical sector) the opportunity for substantial mark-ups.

Increasing provision of health care services is also the product of changing social attitudes. Health care has come to be viewed as a right whose access should not be limited to those who can afford it. Coverage for the elderly and the poor was considerably extended through Medicaid and Medicare legislation in 1966.

Of course, there is no unambiguous definition of health care needs. In addition, there is often a lack of consensus on appropriate treatment even within the medical profession, a difficulty intensified by rapid technological change. A recent Scientific American article reported that different rates of surgery in various regions of the country were often explained by physicians' preferences--not differences in population, hospitals, or environmental or other factors [Wennberg and Gittelsohn, 1982]. Despite tremendous advances in medical knowledge and technology, or possibly because of them, the definition of adequate health care is elusive. So long as coverage is open-ended, demand seems to be unlimited.

The remainder of this chapter is divided into two sections. Section B describes the major components of the health care industry and their representation in the IEA model for the period 1963-1977. The final section describes two explicit scenarios about developments in health care in the United States through the year 2000.

B. The Production and Use of Health Care, 1963-1977

The IEA model includes two health care sectors, Hopsitals (IEA #81) and and Health Services (IEA #82). While the most detailed IO tables decompose the latter sector into two--separating Offices of Doctors and Dentists from the rest--they were aggregated for this study due to the limited availability of systematic data on separate capital and labor requirements.

The conventional IO representation accounts for private and public health care differently, showing public health care as part of final demand. State and local governments operate about 30% of all general hospitals, and another 5% are run by the Federal government, mostly Veterans Administration. While public hospitals provide some services free of charge, their fees for most services are comparable to a market price. In addition, they use inputs and provide outputs similar to those of private hospitals. For these reasons they closely resemble a government enterprise which is usually included inside the IO table as a producing sector. We have included both private and public health care inside the IO table within the two IEA sectors. All health care is assumed to be delivered to households.

The final demand column in the IO tables describing state and local government purchases for health, welfare, and sanitation is predominantly hospital service; the total value of its purchases (presumed to measure the value of its output) was added to the deliveries of private hospitals to households. Since the final demand column by convention includes purchases on both current and capital accounts, the detailed information on the input structure for private hospitals both on the capital and the current accounts was used for the combined sector. The small share of hospital services provided by the Federal government has remained in final demand.

The historical data on capital (B and R matrices) and labor (L matrix) requirements for the two health care sectors were computed in the general way described in Chapter 3. Output of the health care sectors was deflated to 1979 prices using the official BLS deflators: the Consumer Price Index (CPI) for the daily service charge in the case of Hospitals and the CPI for total medical care, eyeglasses and laboratory tests, physicians' and dentists' fees in the case of Other Health Services. (In future work we will attempt to measure real output in terms of actual services provided to different categories of patients drawing in part on the voluminous information available in Public Health Service documents and specialized studies such as those cited among the references for this chapter.)

The remainder of this section is divided into three parts describing structural change in different parts of the health care system in the 1960's and 1970's. This serves as background for the scenarios in Section C about prospects for the next twenty years.

1. Hospitals

During this century hospitals have been providing an increasing amount of health care. While the number of physicians per 100,000 population declined from 176 in the year 1850 to a low of 131 in 1965, rising slowly to 172 by 1978, the number of general hospital beds per 1,000 population has risen from 2.9 in 1920 to 5.0 by 1976 and total days of hospital care increased three-fold between 1930 and 1976 [U.S. Department of Commerce, 1975; U.S. Department of Health, Education and Welfare, 1974b, 1976b; U.S. Department of Health and Human Services, 1979b, 1981].

Data describing the changing utilization of hospitals[1] between 1963 and 1976 are assembled in Table 7.2. While the number of hospitals has declined slightly, the average number of beds per hospital grew by 39% over this period. Beds per

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[1] This discussion is about general, short-term, acute-care hospitals. Specialty and long-term care hospitals provide mainly psychiatric or tuberculosis care.

1,000 population has leveled off at about 5, which is the official government target. The number of days of care (which excludes outpatient and emergency room care) has increased by 8% while the average length of stay has declined by the same amount, and the number of discharges per 1,000 population was 14% higher in 1976 than a decade earlier.

Table 7.2. Utilization of Short-Term Hospitals, 1963-1976

	1963	1967	1972	1976	Percentage Change 1963-1976
Total Hospitals	6,710	6,685	6,491	6,361	-5%
Total Beds	811,876	958,729	1,044,064	1,068,828	32
Beds per 1,000 Population	4.3	4.9	4.9	5.0	16
Average Beds per Hospital	121	143	161	168	39
Number of Days of of Care (1,000's)	227,136[a]	238,703	243,528	245,110[b]	8
Discharges per 1000 Population	NA	146.9	158.3	167.7	14[c]
Average Length of Stay	7.8[a]	8.4	7.7	7.2[b]	-8

[a] in 1965
[b] in 1979
[c] 1967-1976
Sources: [U.S. Department of Health, Education and Welfare, 1974b, 1976b; U.S. Department of Health and Human Services, 1979b, 1981].

The services provided by a hospital during a typical "day of care" have shifted significantly due to changes in medical practice and in demographics. The rate of surgery per 1,000 population has increased 42% in the decade of the 1970's, from 78 to 111. The declining birthrate has reduced the relative incidence of childbirth, which used to be the leading cause of hospitalization. (Newborn infants are not included in the number of discharges.) The median age of the population has been steadily increasing, and the growing proportion of older people--especially women--has distinct health care requirments.

The combination of a shorter average length of stay and a higher rate of surgery has been accompanied by an increased amount of direct care, paper work and other support services per patient as well as intensified use of various types of equipment. Table 7.3 shows the growth in number of medical services per case between 1951 and 1971.

Comparison of the input structures according to the IO tables for 1963, 1967 and 1977 makes it possible to identify the major areas of change. The proportion of nominal costs accounted for by intermediate inputs has increased, with the value-added portion--which is mostly the wage-bill--falling from 67% to 62% between 1963 and 1972. Over the same period, the intermediate costs to produce a given level of output grew by over 40% in real terms (in 1979 prices) since the unit price increase for the output of hospitals is greater than that for virtually all of its inputs (according to the BLS deflators). While food and drugs are major inputs, the largest increases are for services including data processing: hospitals have generally contracted out instead of hiring their own programmers. Other purchases which have grown as a portion of total costs

Table 7.3. Number of Medical Services per Case, by Type of Service and Diagnosis, 1951-1971

	1951	1964	1971
LABORATORY TESTS			
Appendicitis, simple	4.7	7.3	9.3
Appendicitis, perforated	5.3	14.5	31.0
Maternity Care	4.8	11.5	13.5
Cancer of the Breast	5.9	14.8	27.4
Myocardial Infarction	NA	37.9	48.5
Pneumonia, Hospitalized	NA	6.7	18.6
X-RAYS			
Myocardial Infarction	NA	1.3	6.3
Pneumonia, Hospitalized	NA	2.5	3.6
Cancer of the Breast, Diagnostic	.7	2.0	2.3
ELECTROCARDIOGRAMS			
Myocardial Infarction	NA	5.4	9.0
INHALATION THERAPY			
Myocardial Infarction	NA	12.8	37.5
Pneumonia, Hospitalized	NA	3.8	2.6

Source: [Scitovsky and McCall, 1976]

are various plastic products, marking a trend toward the use of disposable items especially in food services. Chemicals and petroleum products which are major inputs for clinical laboratory tests have grown more important, reflecting the increase in both the number and utilization of tests. The portion of costs devoted to photographic equipment has also risen, due to increased use of both X-rays and photocopying equipment.

The health industry, especially hospitals, has been a major source of employment growth in the 1960's and 1970's particularly for women and minorities. Table 7.4 indicates an average annual rate of growth of 8.5% between 1960 and

1978 with the most rapid growth (20.4%) between 1966 and 1970, when federal coverage was provided for the poor and elderly. Lower growth for 1970 to 1978 (4.7%) suggests that the surge in demand has leveled off.

Table 7.4. Health Care Employment, 1960-1978

	All Health Care	Hospitals	Hospitals as percent of total	Average Annual Rate of Growth Since Last Benchmark Year	
				All Health Care	Hospitals
1960	1,547,600	1,030,000	66.6%	---	---
1966	2,206,500	1,418,500	64.3%	6.1%	5.5%
1970	4,630,900	2,960,400	63.9%	20.4%	20.2%
1978	6,698,400	3,900,300	58.2%	4.7%	3.5%

Source: [U.S. Department of Labor, 1980].

The health care work force includes those directly deliverring care, clerical workers, and service workers. Health care practitioners are defined to include physicians, optometrists, pharmacists, podiatrists, veterinarians, and registered nurses; the remainder are often called allied health workers.

Hospital labor requirments per unit of output (i.e., labor coefficients) for physicians and surgeons and for registered nurses have not changed much between 1963 and 1977. Other practitioners are not separately identified in the IEA occupational classification scheme.

Allied health personnel account for about two-thirds of the industry's workforce and grew more rapidly than any other part of the national workforce between 1966 and 1978 [Sekscenski, 1981; U.S. Department of Health and Human Services, 1979a]. The complexity of their training requirements and of their responsibility has also increased. More than a hundred allied health occupations have been distinguished; often a new occupation is created for each new type of medical technology, and many take on work previously done by practitioners. The IEA occupational classification scheme distinguishes Health Technologists (LAB #13), requirements for which have grown significantly between 1963 and 1977; other allied health occupations are dispersed among clerical and service categories.

In the 1960's allied health workers learned their skills through in-hospital training, and almost none were licensed. Due to technological change accompanied by increased areas of responsibility, the need for "middle-level" health practitioners has emerged in areas such as medical record-keeping and clinical laboratories. Numerous specialties require college level training, and regulation by licensure is also growing.

A nurse practitioner, nurse midwife, or physician's assistant is said to increase the number of visits a physician can attend to by 25-30%--even more in group practice [U.S. Department of Health and Human Services, 1979c; U.S. Department of Health, Education, and Welfare, 1974a]. At present there are very few such "physician extenders," and rapid growth in their use for hospital care is opposed by physicians.

Because of the extremely high turnover of RN's in hospitals, various approaches have been formulated (e.g., primary nursing and clinical nurse specialists) to increase their training and expand the scope of their responsibility to include some of the work now done by physicians and some by less skilled LPN's or nurses' aides. In practice, however, it is the role of the LPN that has been expanding [U.S. Department of Health and Human Services, 1979c; U.S. Department Health, Education and Welfare, 1974a].

Health care has traditionally been characterized by a strict division of labor established by physicians' guilds. Many of the factors discussed elsewhere in this section, coupled with a projected oversupply of doctors by 1990, may lead to substantial changes in the organization and responsibilities of health personnel.

Technological change and in particular computer-based automation have affected all aspects of the operation of a hospital. Computers began to be used extensively in hospitals for bookkeeping, billing, inventory control, and patient records following the introduction of Medicare and Medicaid in 1966 which doubled paperwork per patient. It is estimated that today 20-30% of hospital costs are for the handling of this type of information and could be significantly reduced by the increased use of computers [Mahajan, 1979; Paul, 1982].

Hospital laundries and kitchens have become more efficient through the use of larger scale and more automated equipment, the introduction of computer inventory control and menu planning, and shared laundry and purchasing operations among hospitals. At the same time, the widespread use of disposable items, from paper plates to disposable gowns and medical equipment, has drastically reduced the cleaning, sterilization and storage activities.

Health professionals have been reluctant to identify specific cost savings from the application of computers to the delivery of health care, but case studies indicate significant benefits especially in the reduction of congestion and the quality of care. Computers have improved speed and accuracy in controlling test equipment in clinical laboratories. In multiphasic screening centers they handle most procedures in a routine physical exam although their role in diagnosis has been limited [Schwartz, 1982].

A great deal of controversy surrounds the use of many of the new technologies for both diagnosis and treatment because of their high costs in the service of very small, specific patient groups and sometimes their unproven efficacy or undesirable side-effects. Now that the infectious diseases have for the most part been brought under control, the major causes of death are heart disease, cancer, and accidents. Prevention through control of diet, smoking, and unsafe work conditions has not been the major focus of modern medical research.

Cobalt radiation therapy is an increasingly common treatment for cancer. Its high cost is due to both the equipment itself and the need to shield staff and surrounding population [Russell, 1979]. Of the 430 people per 100,000 population treated for cancer each year, 70% receive cobalt therapy. It is a short-term palliative with very serious side-effects whose benefits are difficult to assess.

Open heart surgery requires expensive equipment and extensive supporting staff and facilities. In the late 1960's surgeons were concerned about underutilization of the equipment, but its use has grown rapidly since then and is now about 150,000 interventions a year [Russell, 1979]. This growth is explained in part by an aging population with increased insurance coverage, in part because the operation is sometimes now performed as a preventive measure.

In 1973 legislation amending Medicare made kidney dialysis for artificial cleansing of the blood costless for the patient. By 1976 about 32,000 patients were being treated at the cost of $684 million, and the number of patients is expected to grow to 60,000 by the mid-1980's [Altman and Blendon, 1979].

Computerized axial tomography (CAT) scanning is a diagnostic procedure using a conventional X-ray source and injection of a contrast material; a computer processes and displays the image in narrow cross-sections. It is considered as accurate as alternative procedures and probably exposes the patient to less risk. The first scanner was installed in the U.S. in 1973 and by mid-1976 317 had been installed with another 335 on order. The average machine at that time cost about $450,000 [Altman and Blendon, 1979]. Considerable economies of scale encourage frequent use, perhaps more than warranted, at a cost of at least $200 per scan.

Ultrasound technology, used extensively for diagnosis in obstetrics and cardiology, is one of the bright spots among recent technological developments. The computer analyzes sound waves to produce an accurate image of internal structures at low cost and little or no risk to the patient. It is now standard hospital equipment, and new uses are still being discovered.

Positron emission tomography and nuclear magnetic resonance (NMR) are two new imaging techniques that have not yet been marketed. NMR may replace CAT scanners, providing more information and at less risk to the patient. A nuclear magnetic resonator costs between $1 and $1.5 million.

An important structural change in the organization of health care delivery has been the emergence of the intensive care unit (ICU). In 1962 only one hospital in eighteen had an ICU. By the mid 1970's over 5% of all hospital beds were in ICU's and every hospital had at least one such unit [Russell, 1979]. ICU's group patients in critical condition into coronary, stroke, respiratory, renal, burn, neonatal, pediatric and poisoning care units where their treatment involves more labor, equipment, and space than could be devoted to them on a regular ward. An ICU often has its own EKG, X ray and laboratory units, computers and closed circuit TV. The nursing staff is typically more skilled and three times as numerous (per patient) as on a regular ward.

In what has traditionally been a not-for-profit, decentralized industry, there is a growing trend toward larger, more consolidated and often specialized hospitals, and a shift to for-profit status [Shonick, 1981]. With the increasing importance of expensive, specialized equipment, these organizational changes are intended to reduce duplication and bureacracy and achieve economies of scale at a time when hospital management is under increasing pressure, from private health insurers and government legislators, to reduce costs.

2. Offices of Doctors and Dentists

Between 1965 and 1978 the number of doctors per 100,000 population rose from 131 to 172 and the number of dentists increased from 47 to 53 (see Table 7.5). At the same time the proportion of specialists has grown, and group practice has become an increasingly common arrangement.

Despite the increasing supply of doctors and dentists, Table 7.6 shows that the rate of utilization has not changed much since 1963 when per capita visits numbered 4.8 to the doctor and 1.6 to the dentist. The nature of consultations with physicians, however, has changed with the virtual elimination of the home visit.

Table 7.5. Doctors and Dentists per Capita, 1965-1978

	Doctors Per 100,000 Population	Dentists Per 100,000 Population
1965	131	47
1970	137	47
1972	146	47
1978	172	53

Sources: [U.S. Department of Commerce, 1968, 1981; U.S. Department of Health, Education and Welfare, 1974b; U.S. Department of Health and Human Services, 1980, 1982].

Although Offices of Doctors and Dentists are the most labor-intensive of the health care sectors, the value-added share of nominal costs has declined from 84% to 77% between 1963 and 1972. This is in part explained by the growth of group practices involving sharing of clerical, nursing, and laboratory personnel and of capital equipment. In addition, there is increasing use of less expensive, non-physician labor.

The use of dental auxiliaries has increased tremendously from 70 per 100 dentists in 1950 to 122 in 1976 [U.S. Department of Health and Human Services, 1980; U.S. Department of Health, Education and Welfare, 1974a], and all dentists are now trained in "four-hand dentistry" involving at least one auxiliary. Studies have shown that a dentist with no auxiliaries treats about 30% fewer patients than the average dentist with up to three auxiliaries. Unfortunately, both dentists and their auxiliaries are included in a single residual category (Other

Table 7.6. Visits to Doctors and Dentists, 1963-1979

	Total Visits (millions)		Visits per Capita	
	Doctors	Dentists	Doctors	Dentists
1963	844	294	4.8	1.6
1967	831[a]	260[b]	4.3	1.3
1974	1,025	342	4.9	1.7
1975	1,056	341	5.1	1.6
1979	1,022	366	4.7	1.7

[a] July 1966 - June 1967
[b] 1968
Sources: [U.S. Department of Commerce, 1968, 1981: U.S. Department of Health, Education and Welfare, 1974b].

Medical Professionals, LAB #12) in the IEA occupational classification.

The services--especially medical services--represent a larger share of costs for Offices of Doctors and Dentists than do manufactured goods. There is also large and growing input from personal and repair services, miscellaneous business services, and professional services--more lawyers, accountants, billing agencies, and servicing for a growing amount of sophisticated equipment. The most rapidly growing input to this industry is insurance.

Of the manufactured inputs, periodicals and book publishing are the only significant goods not directly related to medical care. Drugs and petroleum products are both important. Surgical instruments and supplies, including syringes, bandages, cotton and all kinds of tools and equipment, have been increasing rapidly, reflecting new techniques and increased use of disposables. Many instruments, for example scalpels and syringes, are now disposable.

3. Other Health Services

Other Health Services is a heterogenous sector. The largest single component is the nursing home industry[2]; independent medical and dental laboratories, birth control clinics, blood banks, visiting nurse associations, all nonphysician licensed health practitioners, and health maintenance organizations (HMO's) are also included.

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[2] This will for the first time be disaggregated as a separate sector in the official 1977 IO tables due to be released by the BEA later this year.

The rapid growth in the use of nursing homes is illustrated in Table 7.7. This can be explained by the aging of the population, the tendency of older Americans to live in households separate from their children, and Medicare coverage for nursing homes starting in 1966.

Other components of this sector have also been growing rapidly. the number of HMO's rose from 20 in 1965 and 26 in 1970 to 265, with 10.5 million members, by 1980. Overall costs to members are estimated to be 15-20% lower than for other forms of delivery [Business Week, 1982].

As of 1969 independent laboratories were by law allowed to be headed by licensed non-physicians. In addition, the large array of new diagnostic techniques has been accompanied by increased demand for laboratory services. As a consequence, the number of independent laboratories has grown considerably.

Table 7.7. Nursing Homes, 1963-1973

	1963	1967	1971	1973	Percentage Change 1963-1973
Number of Facilities	16,701	19,141	22,004	21,834	31%
Beds (1,000's)	569	837	1,202	1,328	133
Residents (1,000's)	491	756	1,076	1,198	144

Sources: [U.S. Department of Health, Education and Welfare, 1974b].

In 1975 there were 15,000 clinical laboratories outside of doctors' offices, about half in hospitals and half independent. The latter attained revenues of about $5.5 billion [Altman and Blendon, 1979].

The diversity of this sector, with its changing product mix, obscures a technolgoical interpretation for changes in the cost structure. This is, however, the only one of the three health care sectors for which the value-added share of nominal costs has risen between 1963 and 1972 (from 63 to 68%). The share of services has also been rising consistently, especially personal and repair services, miscellaneous business services, professional services, and other medical services.

The increased share of costs allocated to food and the declining share for surgical supplies in the aggregate sector reflects the growth of full-board, primarily custodial nursing homes. Miscellaneous plastic products, used throughout the sector, grew rapidly. Most dramatic is the increased share of photographic equipment, used both for X-rays and photocopying.

C. The Future Production of Health Care

The scenarios described in this section assume that we will continue over the next two decades to improve the "quality" of health care in the sense of devoting more resources than under the baseline scenario to satisfying the same final demand. This implicitly assumes no major breakthroughs in prevention techniques.

These scenarios are based in part on the extrapolation of those past trends that can be expected to continue, according to the qualitative analysis in the last section of this chapter. The increased use of computers and office equipment and associated changes in employment for administrative operations are discussed in Chapter 5 while the increased use of computers for "production" is described in Chapter 4. Other changes in input structure after 1977 are summarized in Table 7.8 below.

Projections of increased use of specific items of capital through 1990, including CAT scanners and nuclear magnetic resonators, were obtained from market research studies [Gruson, 1982; Portugal, 1982] and are the basis for the increase in capital coefficients shown in the top panel of Table 7.8.

The middle panel of the table shows projected increases in the use of intermediate goods and services. The rates shown are the average annual rates that obtained between 1972 and 1977. The labor coefficients shown in the bottom panel of the table are also assumed to grow at the average annual rate actually experienced between 1972 and 1977.

Under Scenario S3, the average annual percentage increases in coefficients shown in Table 7.8 are compounded over the period from 1978 to 2000. Under Scenario S2, this procedure is followed only through 1990 and the coefficients remained unchanged thereafter.

Table 7.8 Input Structure for Hospitals (IEA #81) and Other Medical and Health Services (IEA #82) under Scenarios S2 and S3[a] 1978-2000 (annual rate of increase after 1977, in percent)

	Hospitals (IEA #81)	Other Medical an Health Services (IEA #82)
Capital Coefficients[b]		
Code Sector		
60 Miscellaneous Electrical Machinery	1.6%	-
64 Scientific and Controlling Instruments	1.3	1.5%
Interindusty Coefficients		
Code Sector		
26 Chemicals	3.7	3.5
28 Drugs	5.8	4.3
30 Petroleum and Related Products	8.1	7.7
31 Rubber	8.1	7.2
64 Scientific and Controlling Instruments	4.2	2.2
65 Optical and Photographic Equipment	8.5	7.9
66 Miscellaneous Manufacturers	4.7	2.2
77 Business Services	8.6	8.0
Labor Coefficients[a]		
Code Occupation		
12 Medical Professionals Other than Physicians and Nurses	1.1	---
13 Health Technologists	2.7	5.7

[a] Under Scenario S2, these annual growth rates are applied to the 1977 coefficients through 1990, and the 1990 matrices are repeated through 2000. Coefficient growth continues at the specified rates through 2000 under Scenario S3.

[b] Increased demand for computers and office equipment and associated impacts on employment are described in Chapters 4 and 5.

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Chapter 8. Final Demand Projections

Deliveries of goods and services to households, public administration activities, and foreign trade have not been described in Chapters 4 through 7. The IEA model is not yet "closed" with respect to these activities and therefore needs to be provided (from outside sources) with projections of the levels as well as the composition of the goods and services they will require. Projected deliveries for investment purposes, on the other hand, are determined within the dynamic model.

For the present study we did not attempt to make original projections of these final deliveries. Instead we relied on the medium growth version of the most recent BLS projections, which takes the form of a matrix with 156 sectors and 13 categories of final demand for each of two benchmark years, 1985 and 1990, in 1972 prices. Labor employed directly by households and government is not included. A discussion of the BLS methodology can be found in [Monthly Labor Review, 1981; U.S. Department of Labor, 1982].

The BLS final demand matrix was aggregated to a single column of noninvestment final demand, inflated to 1979 prices, and again aggregated from 156 to 89 producing sectors for each benchmark year. The resulting final demand vector was interpolated linearly for years between 1977[1] and 1985, and between 1985 and 1990. Sector-specific growth rates for the five-year period between 1985 and 1990 were repeated for the periods 1990-1995 and 1995-2000, and annual final demand was interpolated linearly for the years in between.

---

[1] The preparation of the 1977 final demand vector is included in the work described in Chapter 3.

In addition to modifications of final demand for education and health, which are described in other chapters of this report, some changes were made to reflect growing use of computers by households and the military. Two versions of final demand, differing in the presumed future use of computers in homes and by the government, were prepared in addition to the BLS projections.

At the present time it seems clear that the BLS projections of household use of computers are too low. Considerably higher projections were prepared by the market research organization LINK (reported in [U.S. Congress, 1982]). The first IEA version of final demand used the LINK projections for household computer use until 1986, with the average annual growth rate between 1982 and 1986 extrapolated to 1990. Between 1990 and 2000 we assumed that growth would continue at only half this rate. In the second version of the final demand projections, purchases of computers by households in 1985, 1990 and 2000 are double the low estimates. These assumptions are shown in Table 8.1.

In the first version of the IEA projections, the military use of computers is represented by the BLS estimate. The second version is based on estimates of the future use of computers, software, and related services given in [Electronics Industries Association, 1980]. Half of the software and related services used by the military are purchased from the private sector, shown in our model as an input from Business Services (IEA #77). The use of computers and services in 2000 is extrapolated from 1990 based on the growth rate between 1985 and 1990 anticipated in this source. While these estimates of the military use of computers, shown in Table 8.2, are significantly higher than those prepared by BLS, they are low compared to the present Administration's projected military budgets. This policy may, however, be reversed before 2000.

The results reported in Chapter 1 are all obtained using the second version of final demand projections.

Table 8.1. Household Demand for Computers (IEA #50), Versions 1 and 2, 1980-2000 (millions of dollars, 1979 prices)

	BLS Projections	IEA Version 1	IEA Version 2
1980	$169	$ 494	$ 901
1985	219	1,085	2,170
1990	341	2,424	4,848
2000	584	3,494	6,988

Table 8.2 Military Demand for Computers (IEA #50) and Related Services (Part of IEA #77), Versions 1 and 2, 1980-2000 (millions of dollars, 1979 prices)

	Computer Hardware		Software and Services	
	BLS Projections and IEA Version 1	IEA Version 2	BLS Projections and IEA Version 1	IEA Version 2
1980	366	2,776	590	3,089
1985	377	3,785	819	6,336
1990	670	5,541	1,764	11,810
2000	1,749	11,874	4,603	25,311

8.5

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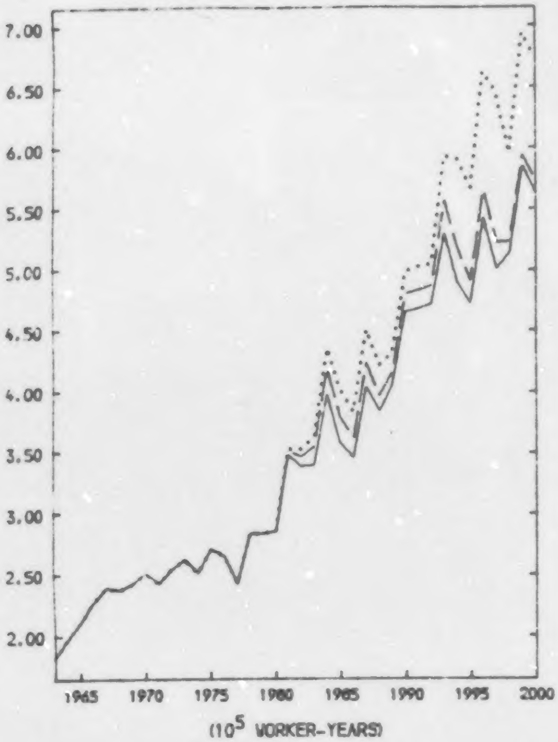
Appendix. Graphic Results under Alternative Scenarios, 1963-2000

Each graph in the five sections of the Appendix displays the values of a particular variable for the years 1963-2000 under alternative scenarios according to the following code:

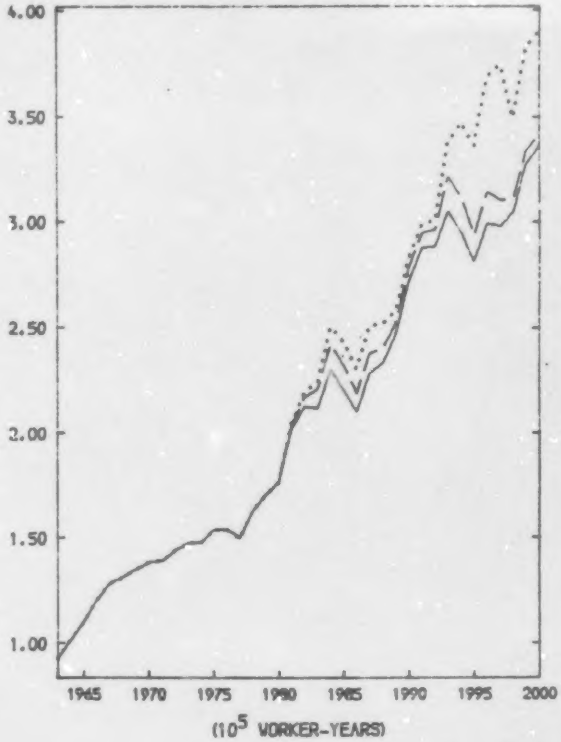
――――――――――	Scenario S1
----------	Scenario S2
....	Scenario S3

The assumptions underlying each scenario are described in Chapter 1, Section B. The occupational and sectoral classification schemes are given in Tables 3.1 and 3.7 of Chapter 3. Time is measured on the horizontal axis; the units on the vertical axis are given under each graph.

A. EMPLOYMENT BY OCCUPATION



1-ELECTRICAL ENGINEERS



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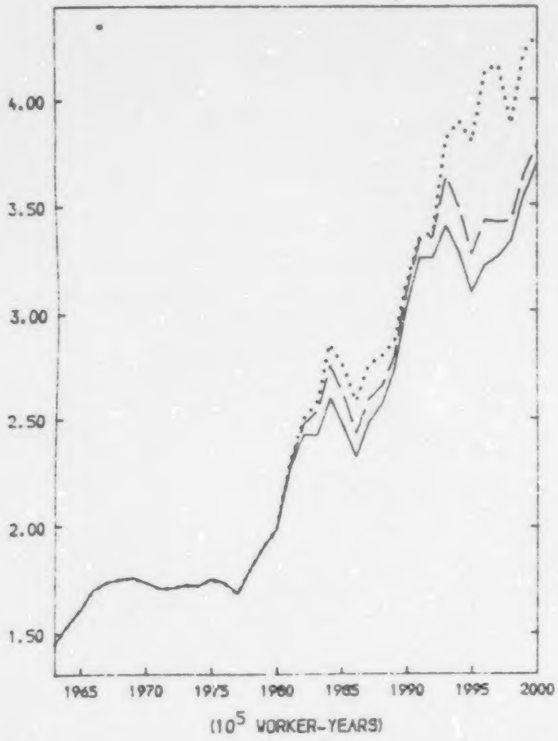
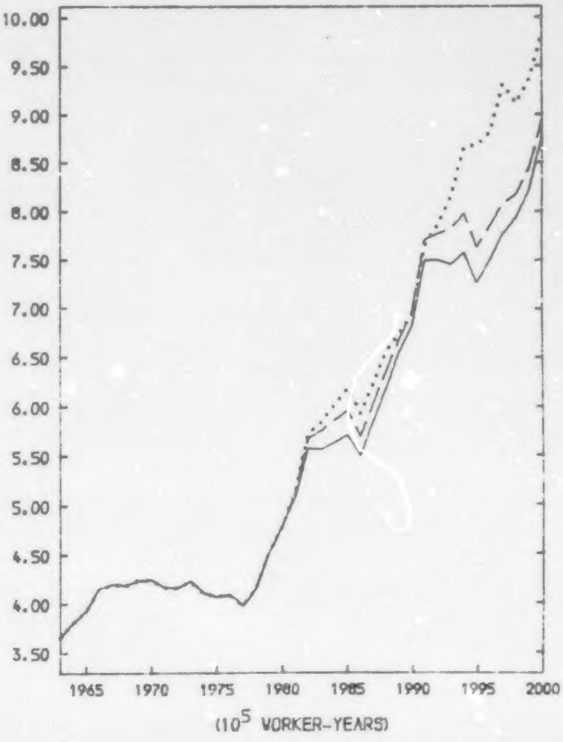
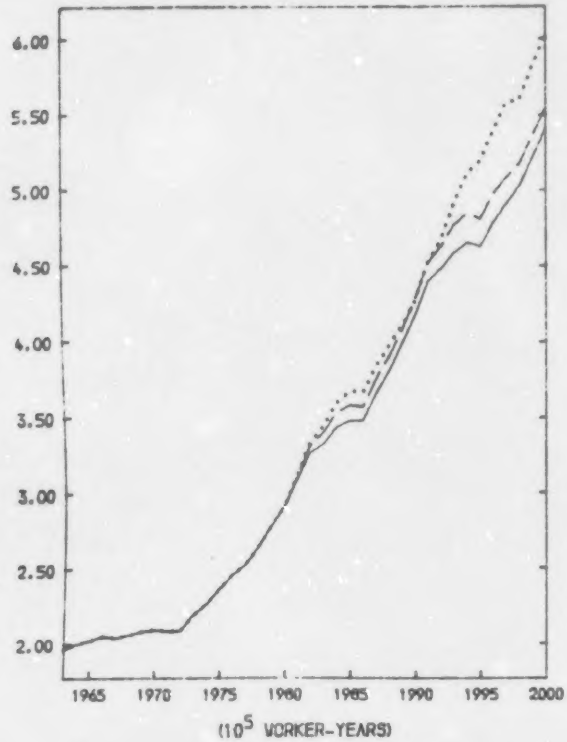


3-MECHANICAL ENGINEERS

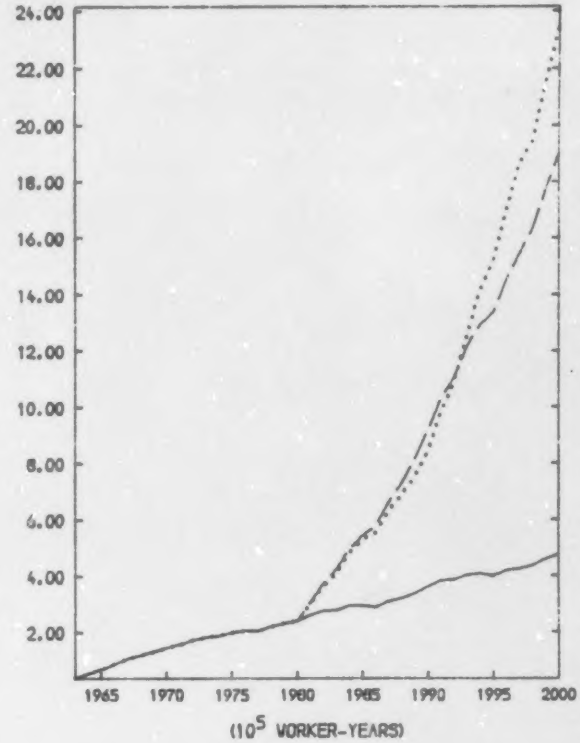


4-OTHER ENGINEERS

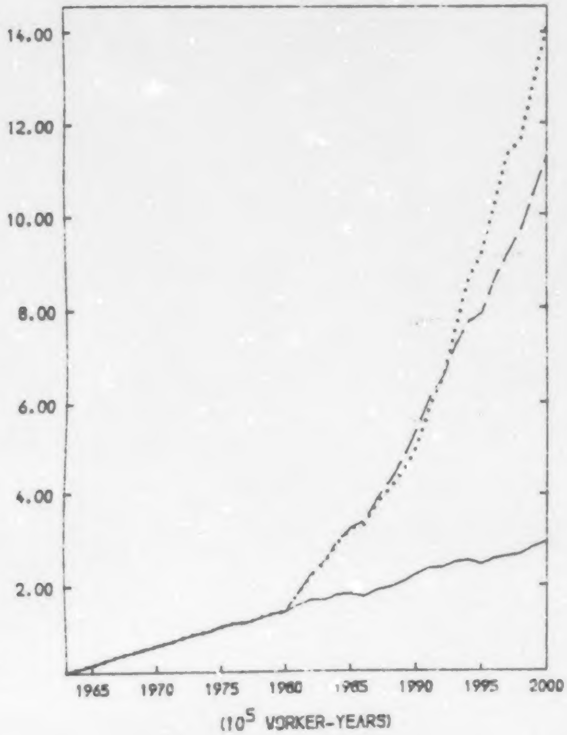
A. EMPLOYMENT BY OCCUPATION



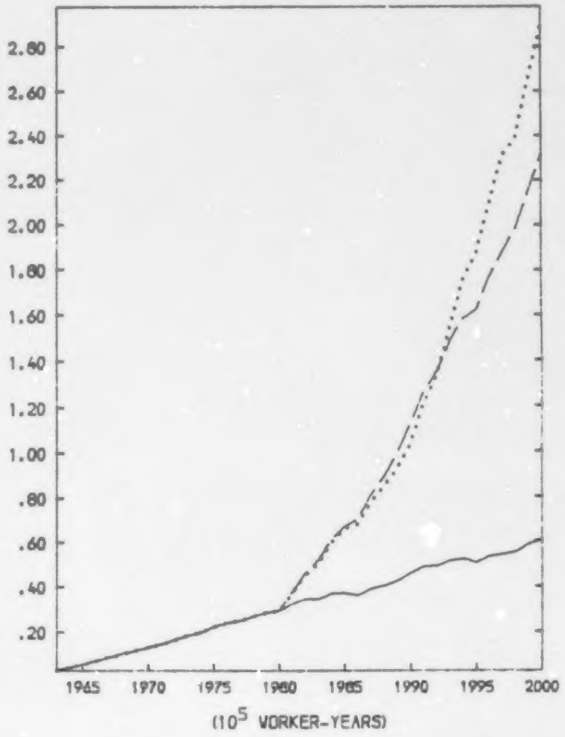
5-NATURAL SCIENTISTS



6-COMPUTER PROGRAMMERS

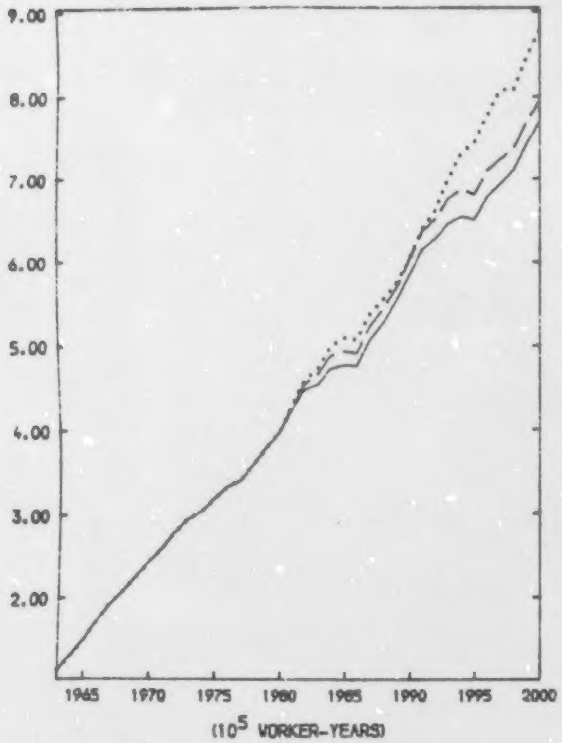


7-COMPUTER SYSTEM ANALYSTS

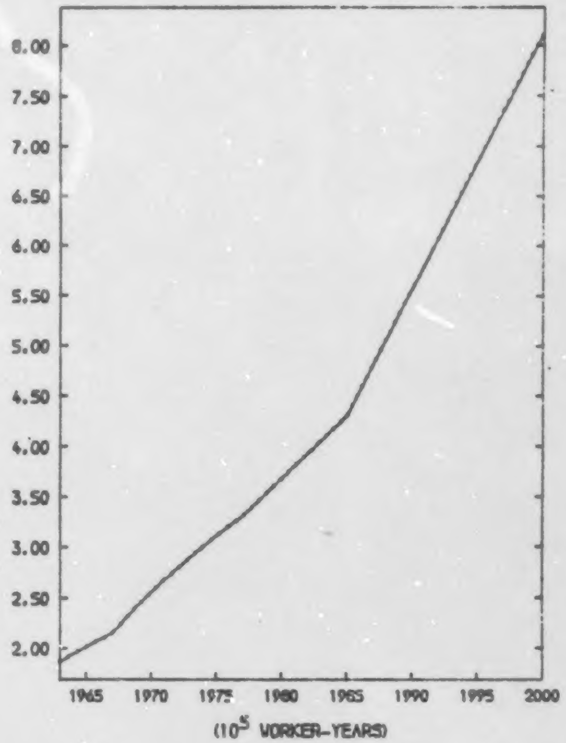


8-OTHER COMPUTER SPECIALISTS

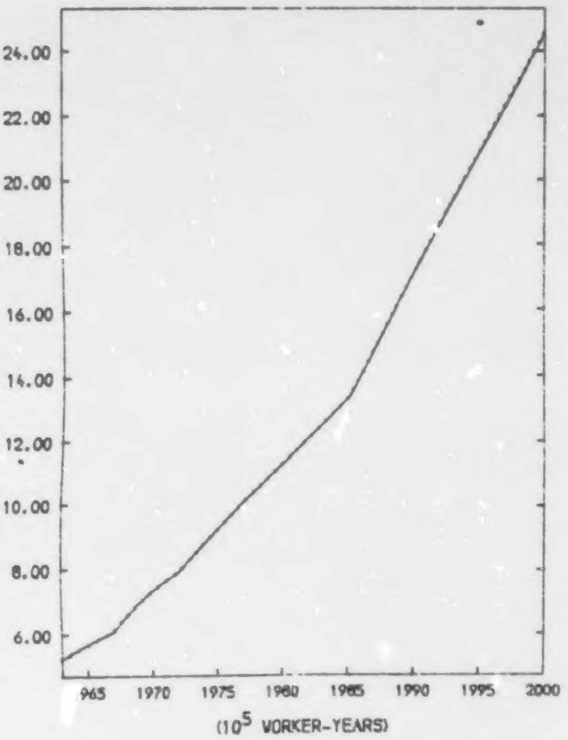
A. EMPLOYMENT BY OCCUPATION



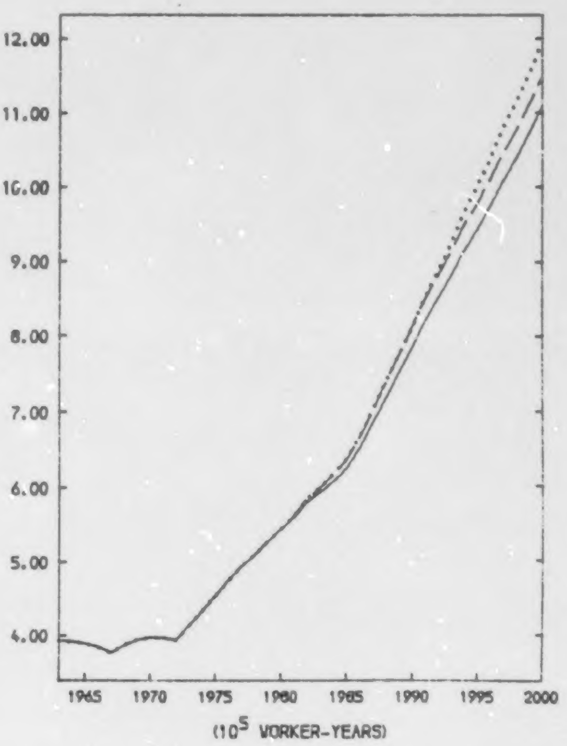
9-LABOR RELATIONS WORKERS



10-PHYSICIANS, SURGEONS

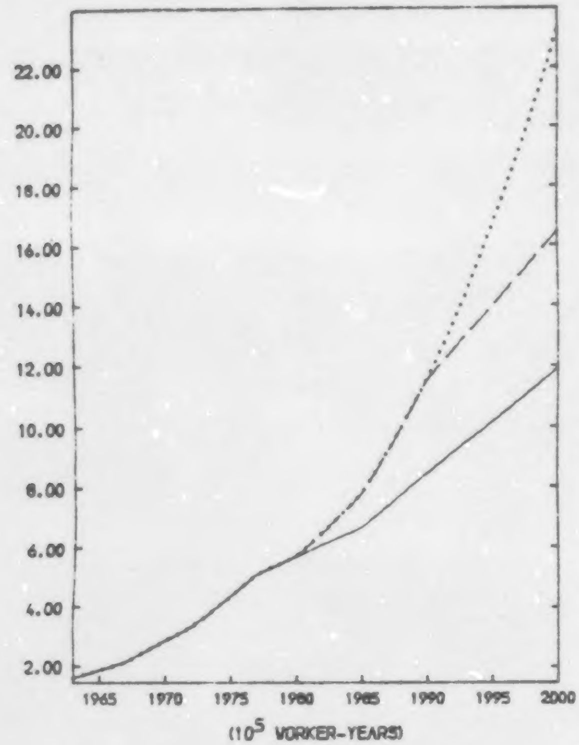


11-REGISTERED NURSES

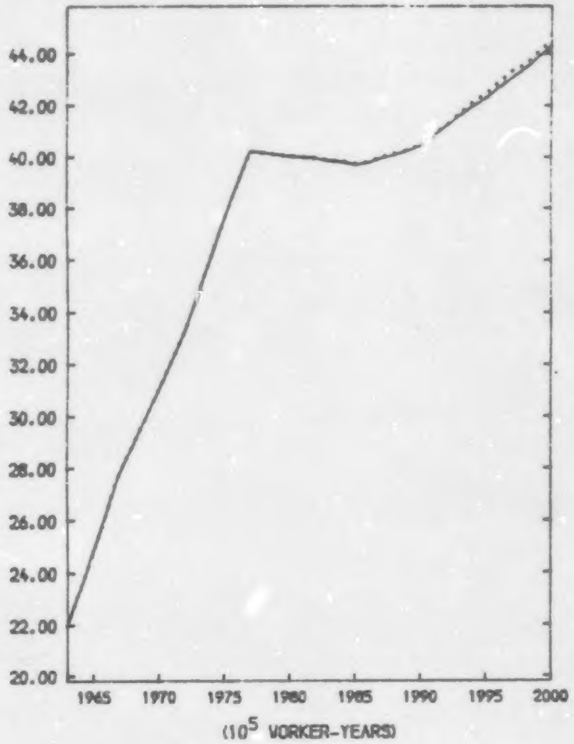


12-OTHER MEDICAL

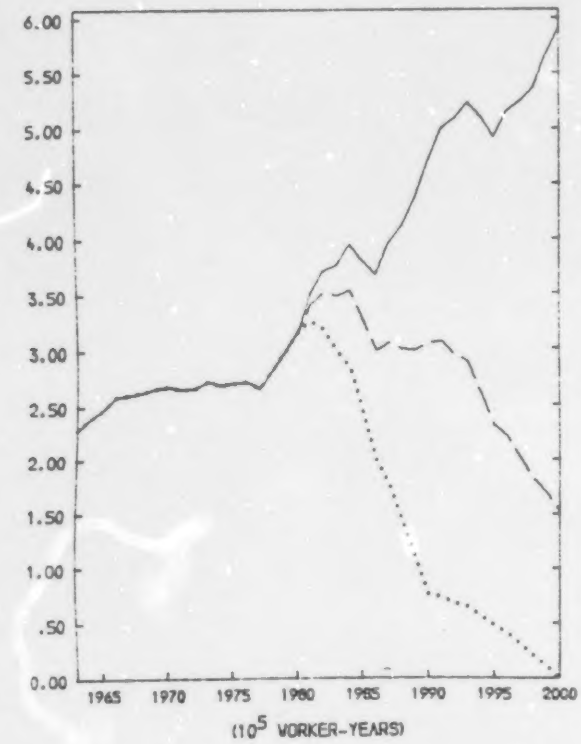
A. EMPLOYMENT BY OCCUPATION



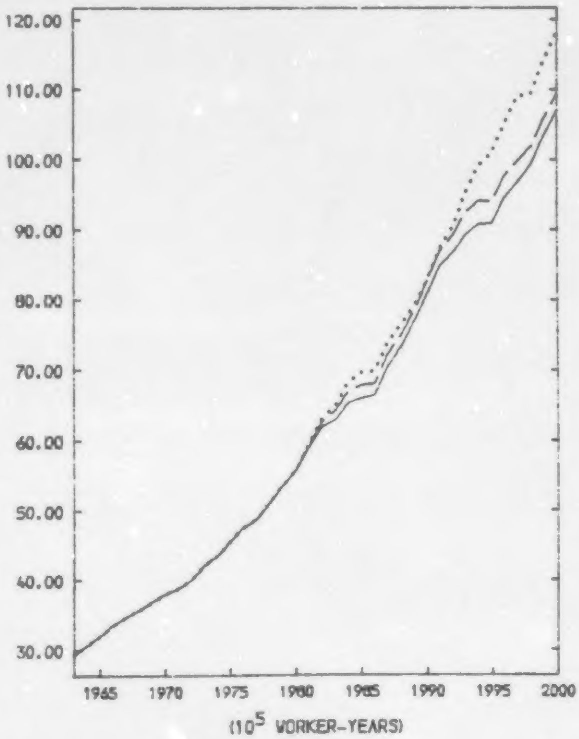
13-HEALTH TECHNOLOGISTS



14-TEACHERS

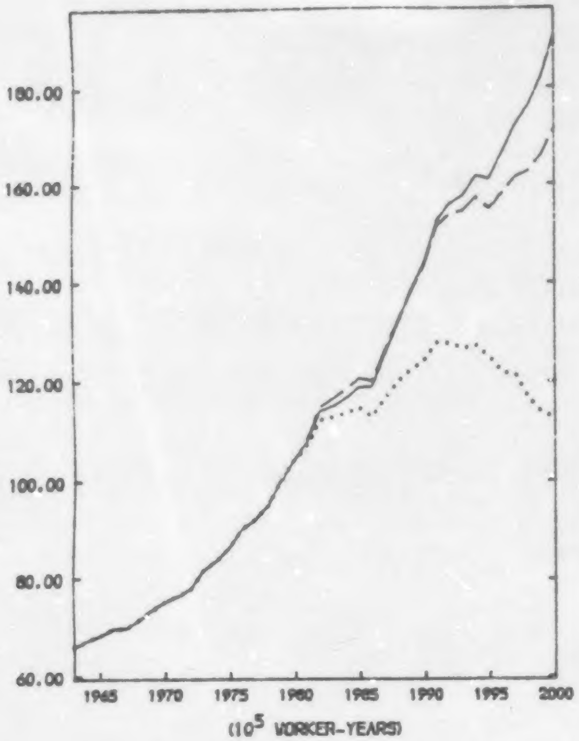


15-DRAFTERS

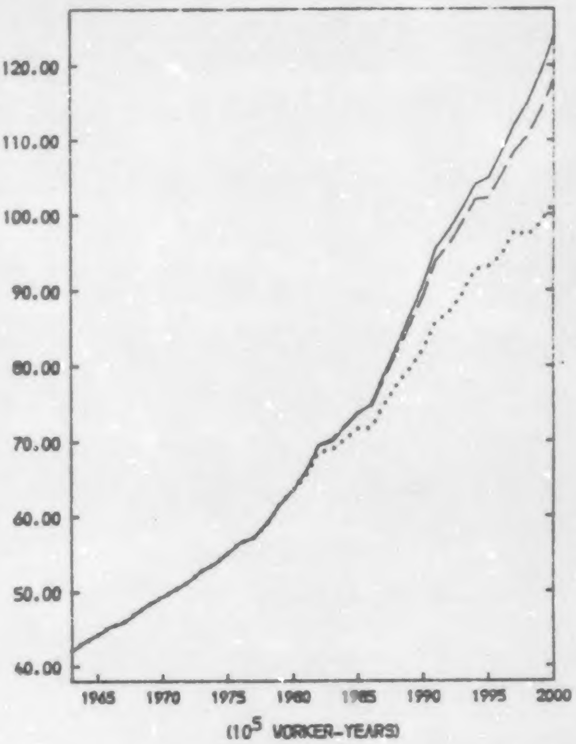


16-OTH PROFESSIONAL, TECHNICAL

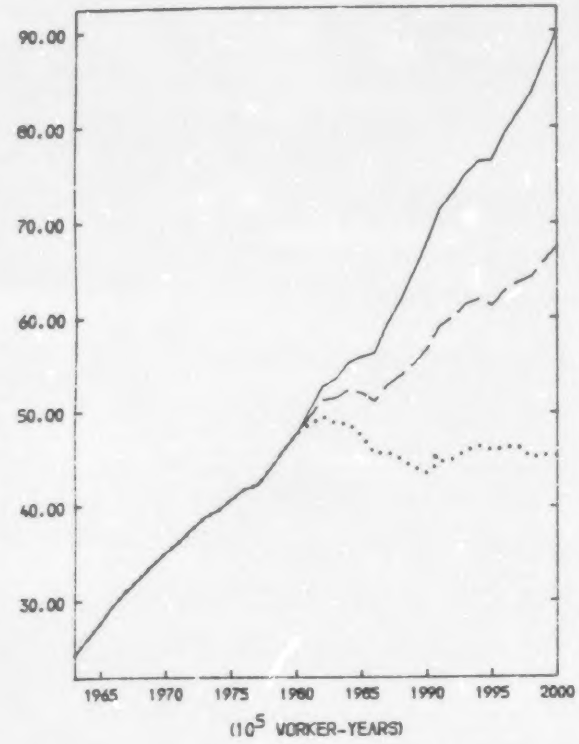
A. EMPLOYMENT BY OCCUPATION



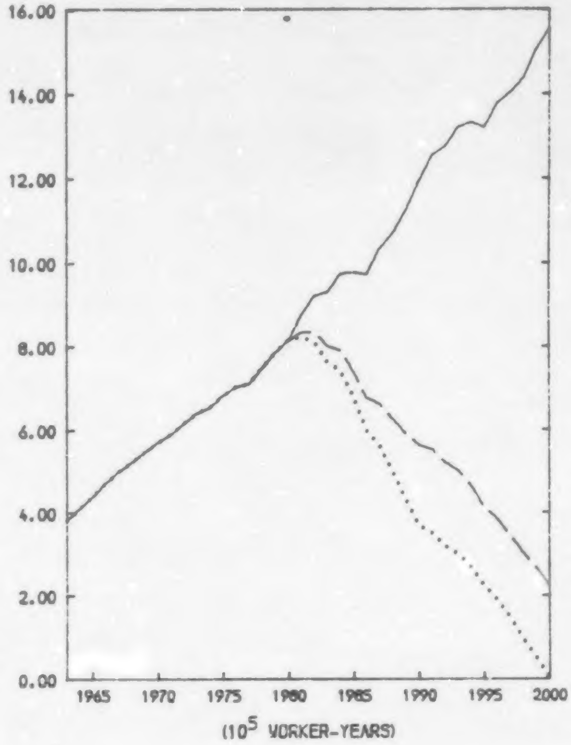
17-MANAGERS, PROPRIETORS



18-SALES WORKERS

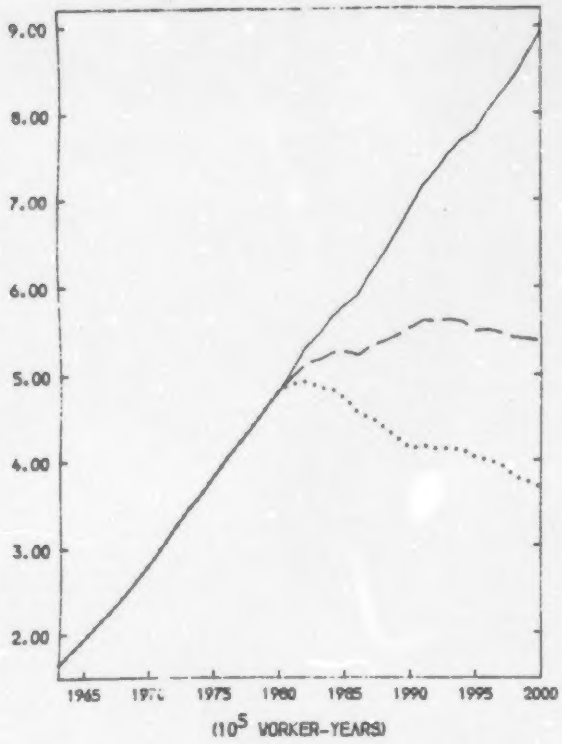


19-SECRETARIES

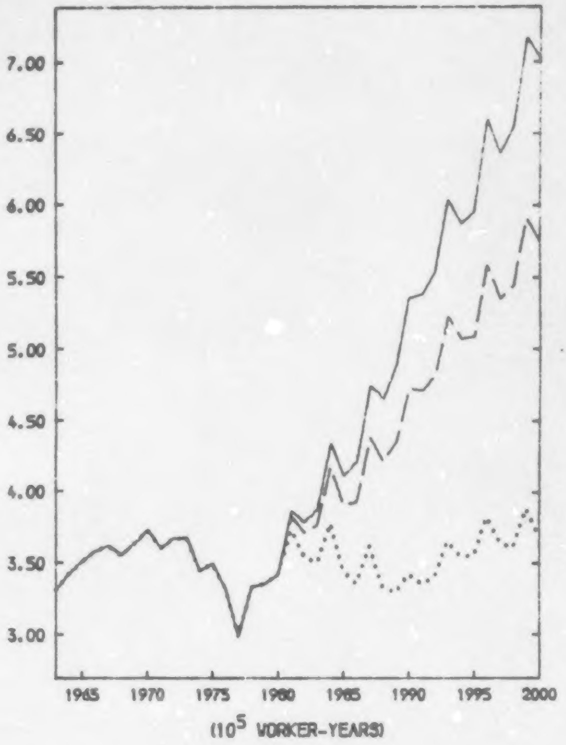


20-OFFICE MACHINE OPERATORS

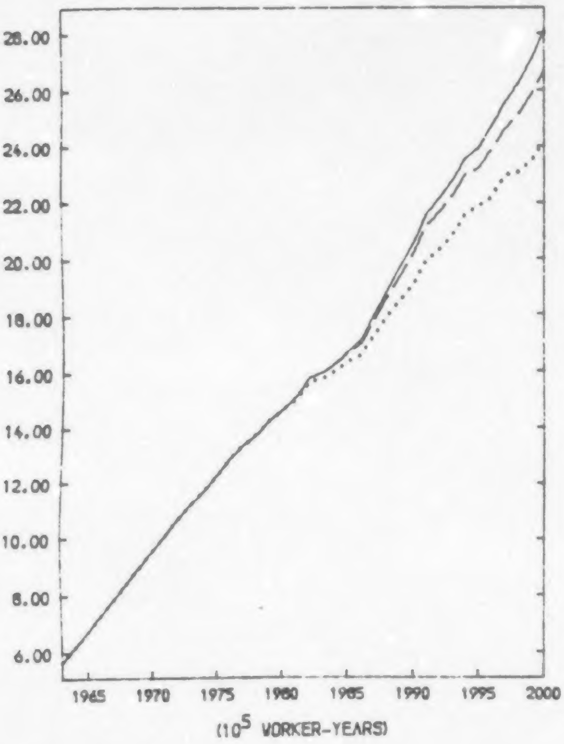
A. EMPLOYMENT BY OCCUPATION



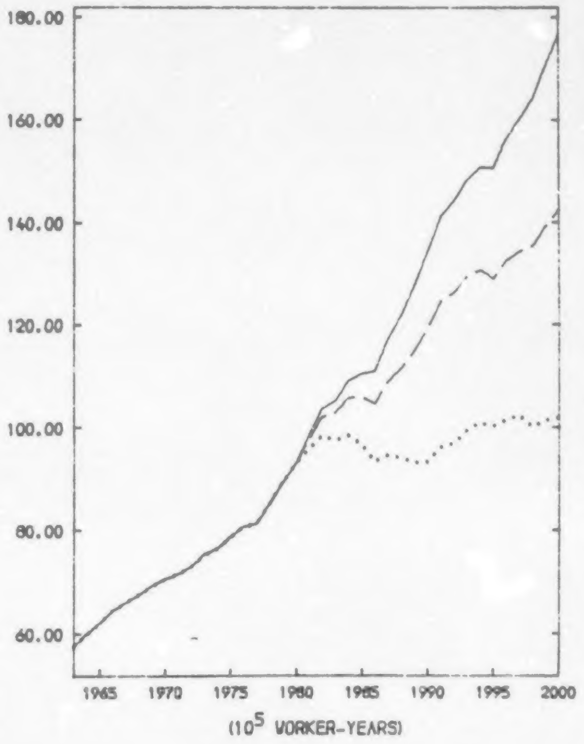
21-BANK TELLERS



22-PHONE OPERATORS

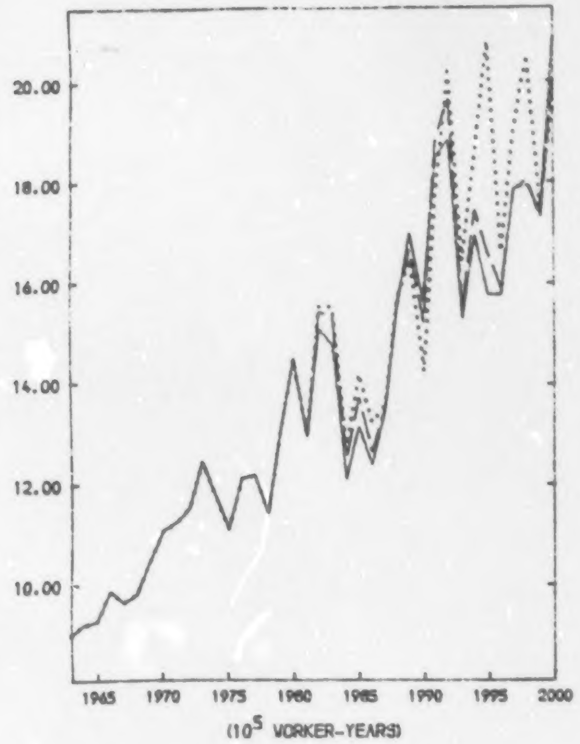


23-CASHIERS

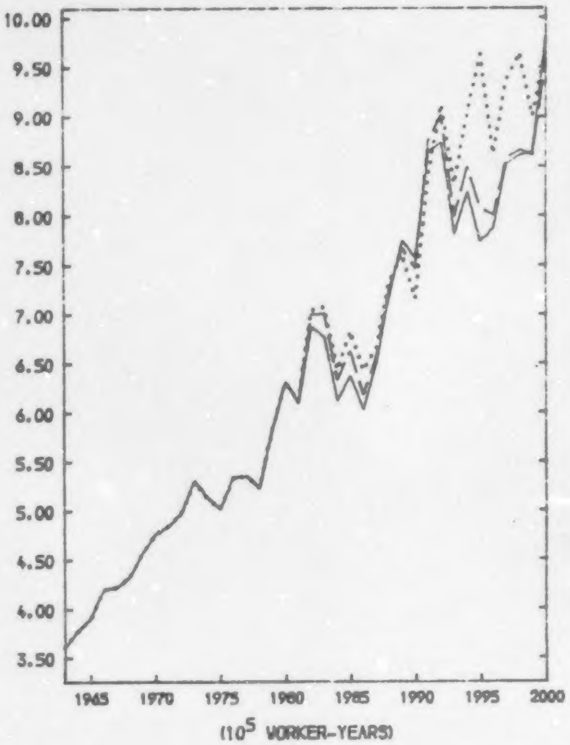


24-OTHER CLERICAL

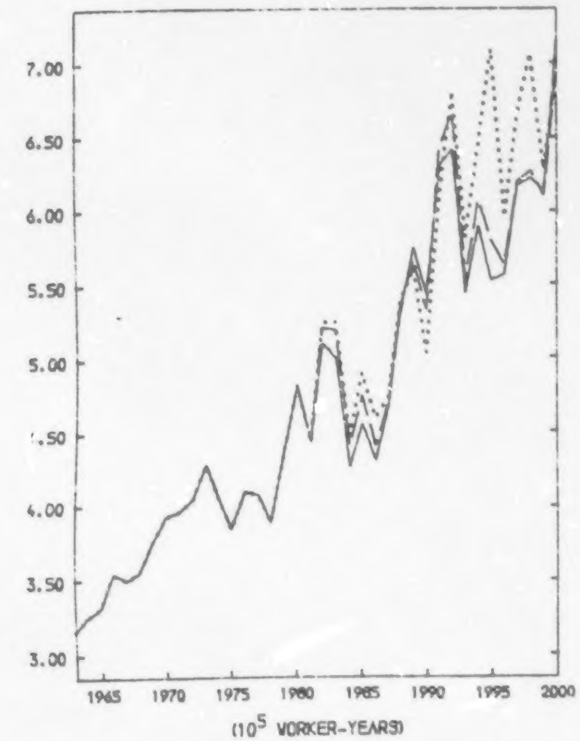
A. EMPLOYMENT BY OCCUPATION



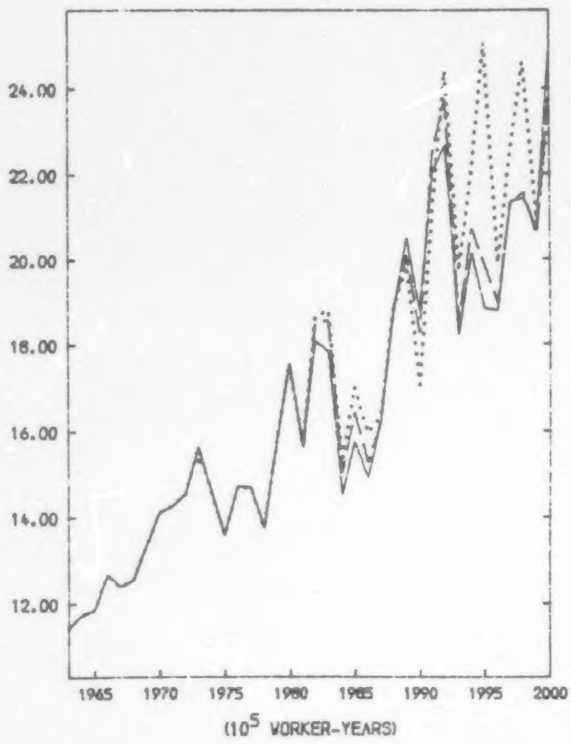
25-CARPENTERS



26-ELECTRICIANS

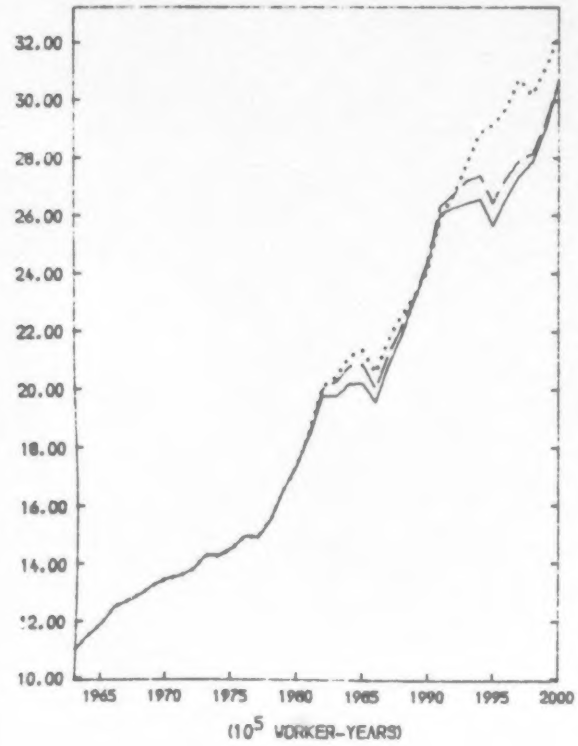


27-PLUMBERS

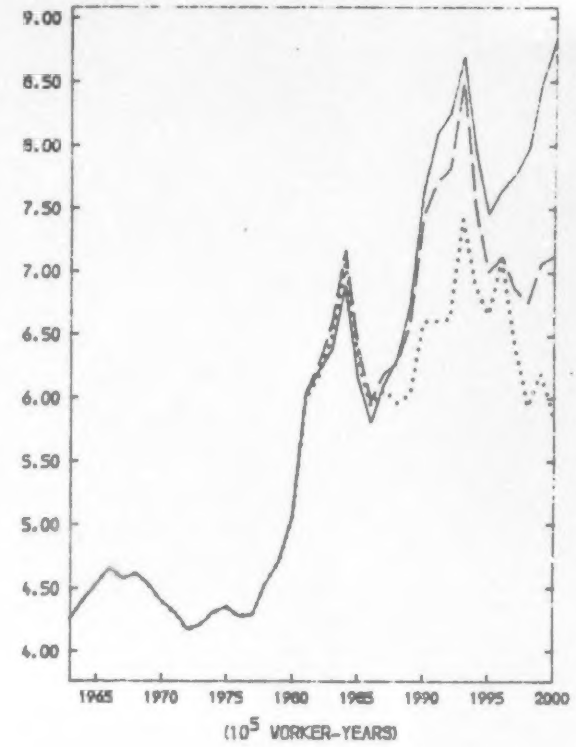


28-OTH CONSTRUCTION CRAFTSMEN

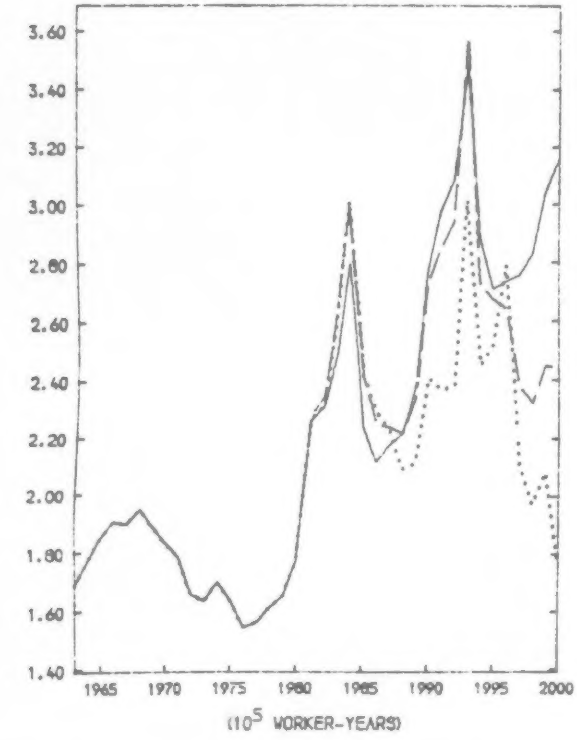
A. EMPLOYMENT BY OCCUPATION



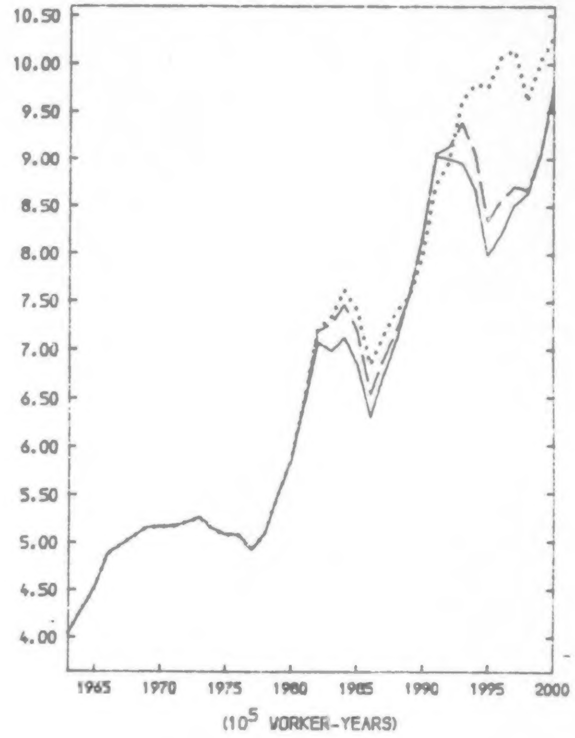
29-FOREMEN



30-MACHINISTS

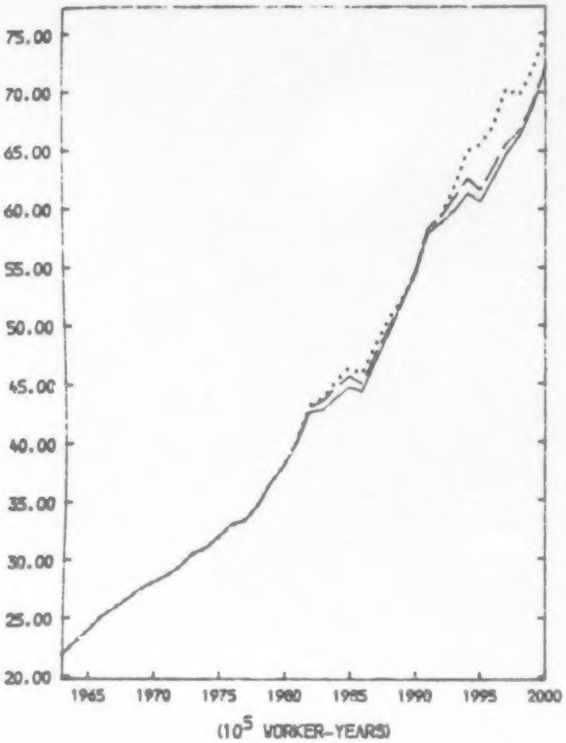


31-TOOL, DIE MAKERS

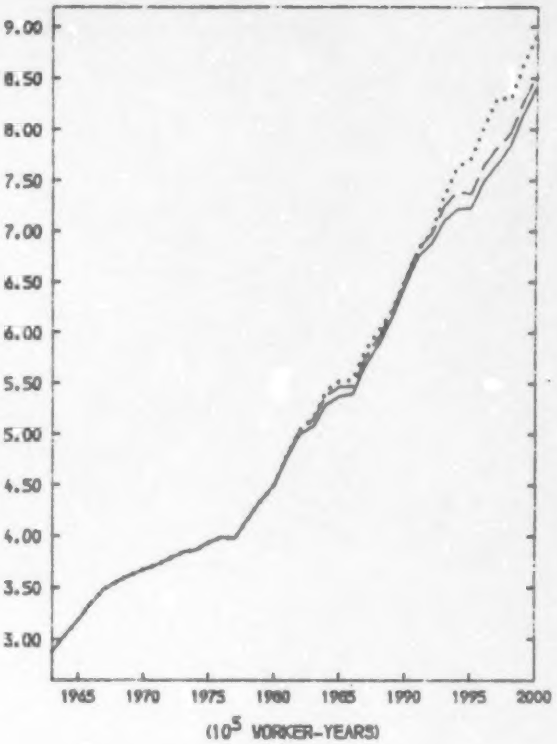


32-OTHER METAL CRAFTSMEN

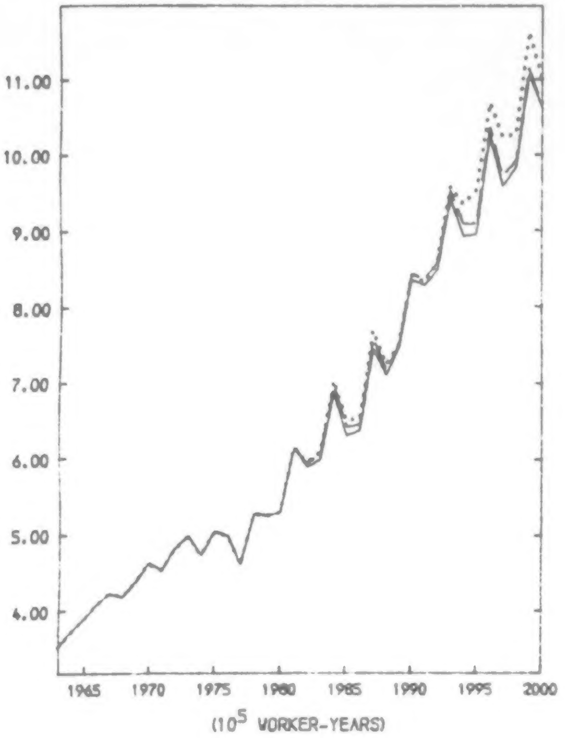
A. EMPLOYMENT BY OCCUPATION



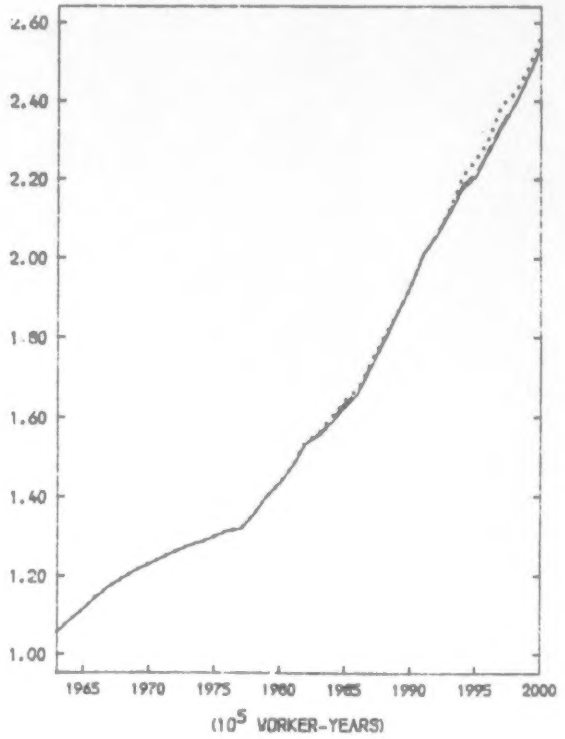
33-MECHANICS, REPAIRERS



34-PRINTING TRADE CRAFTSMEN

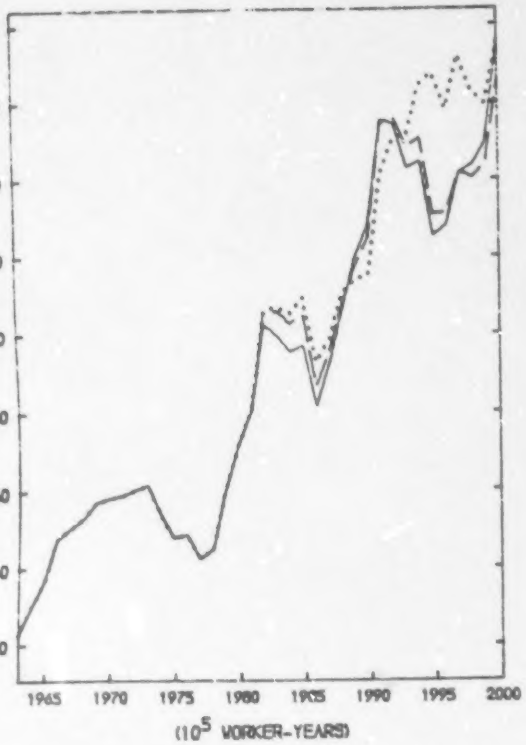


35-TRANSPORTATION WORKERS

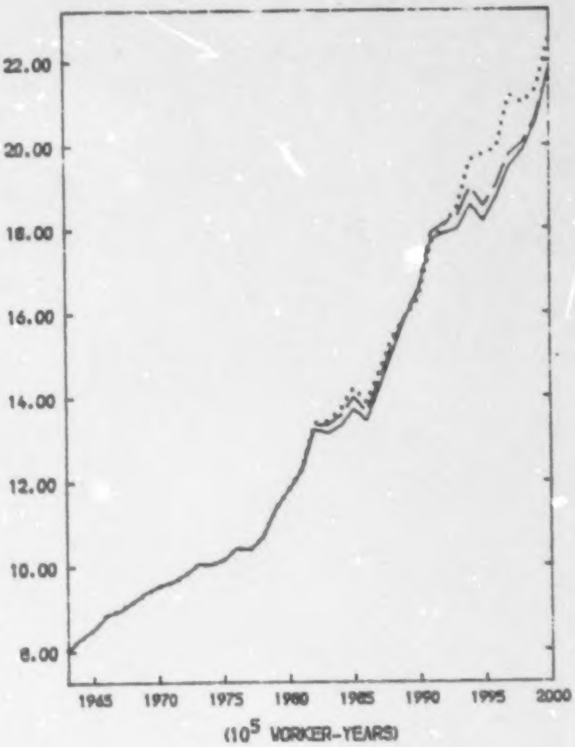


36-BAKERS

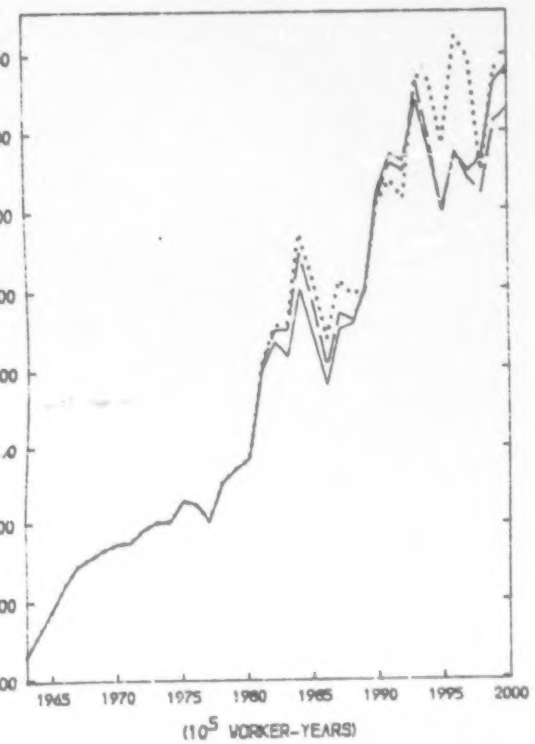
A. EMPLOYMENT BY OCCUPATION



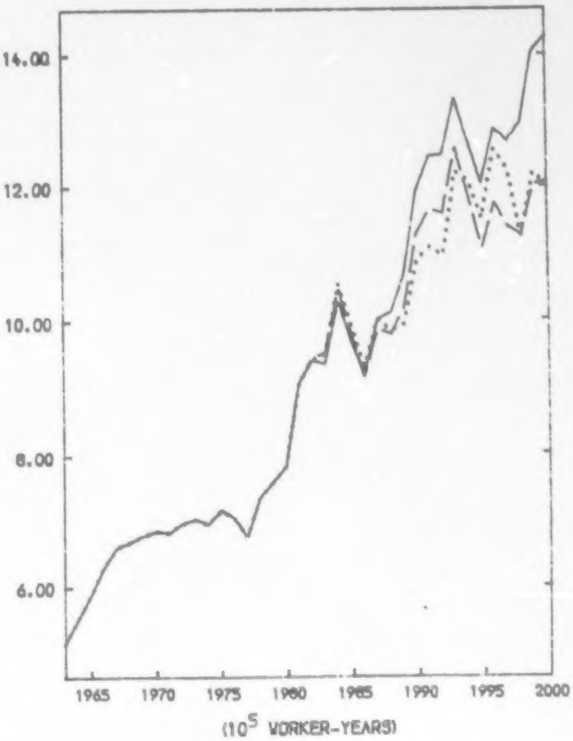
37-CRANE, DERRICK OPERATORS



38-OTHER CRAFTSMEN

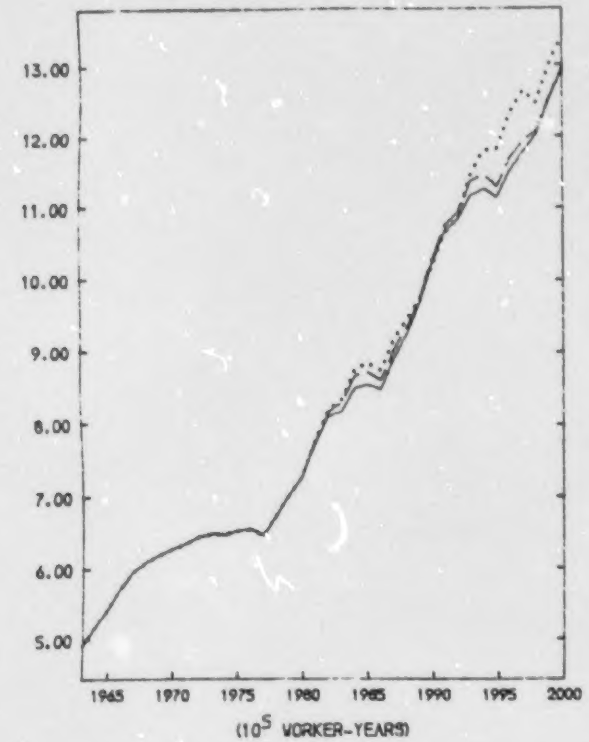


39-ASSEMBLERS

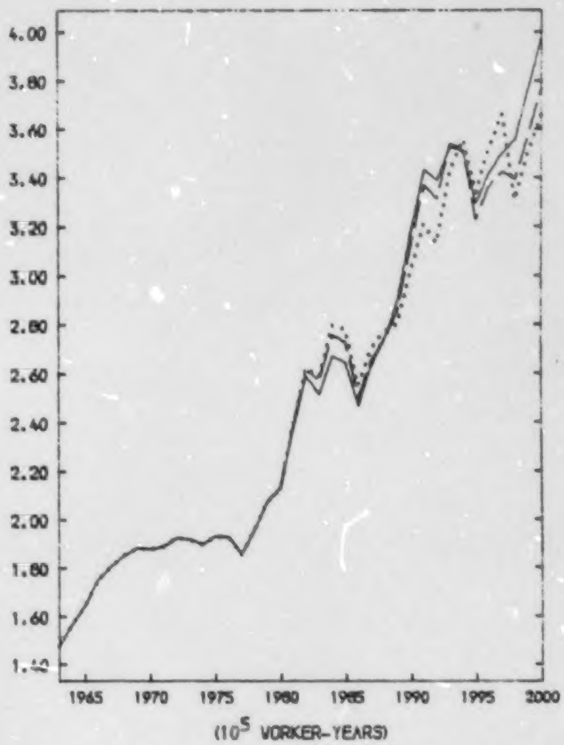


40-INSPECTORS

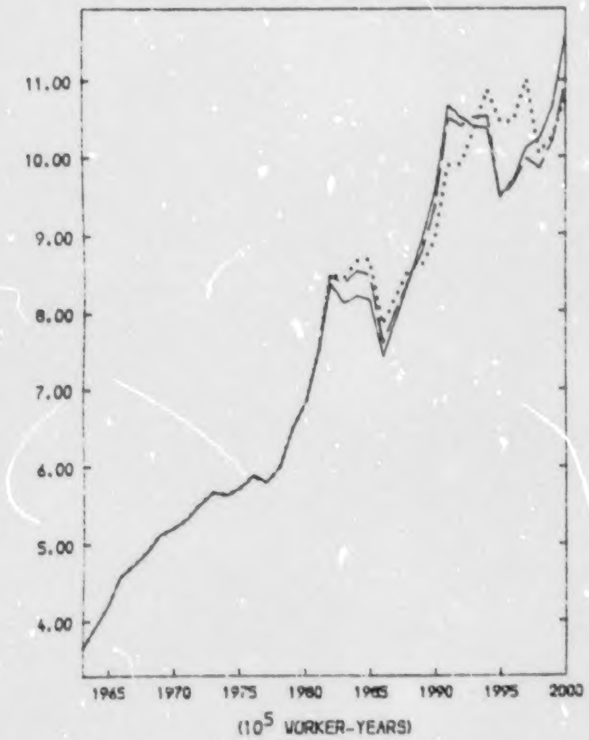
A. EMPLOYMENT BY OCCUPATION



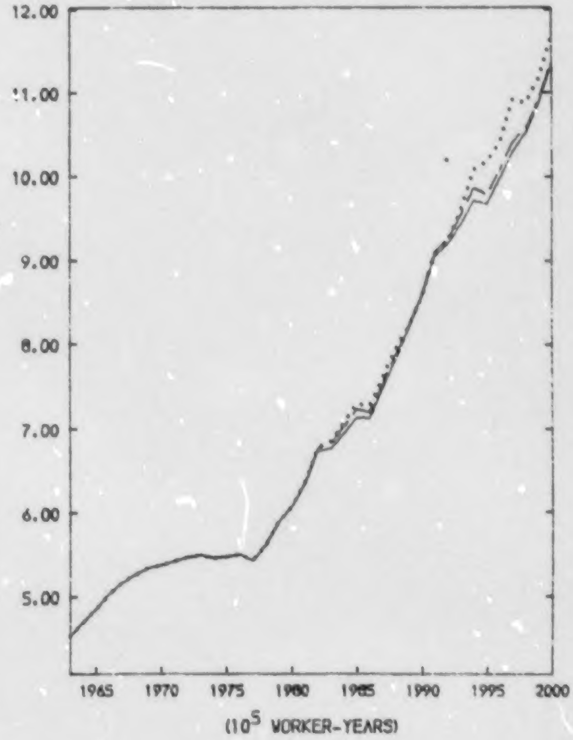
41-PACKERS AND WRAPPERS



42-PAINTERS

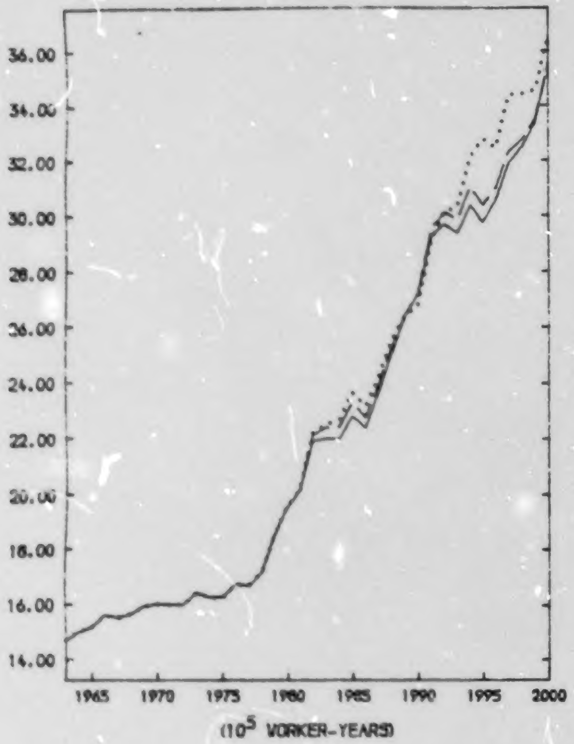


43-WELDERS, FLAME CUTTERS

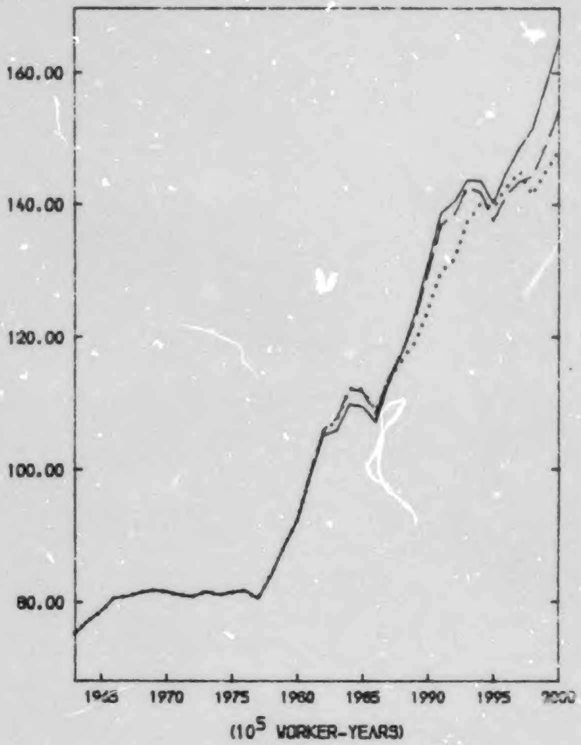


44-DELIVERY, ROUTE WORKERS

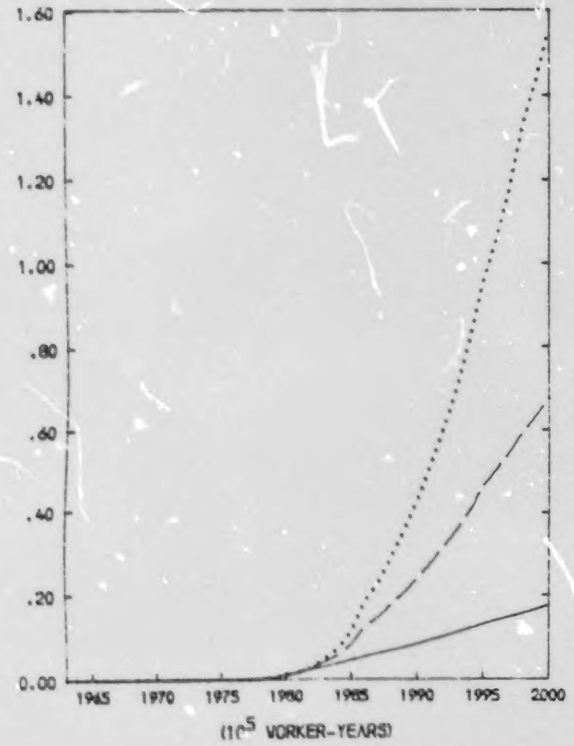
A. EMPLOYMENT BY OCCUPATION



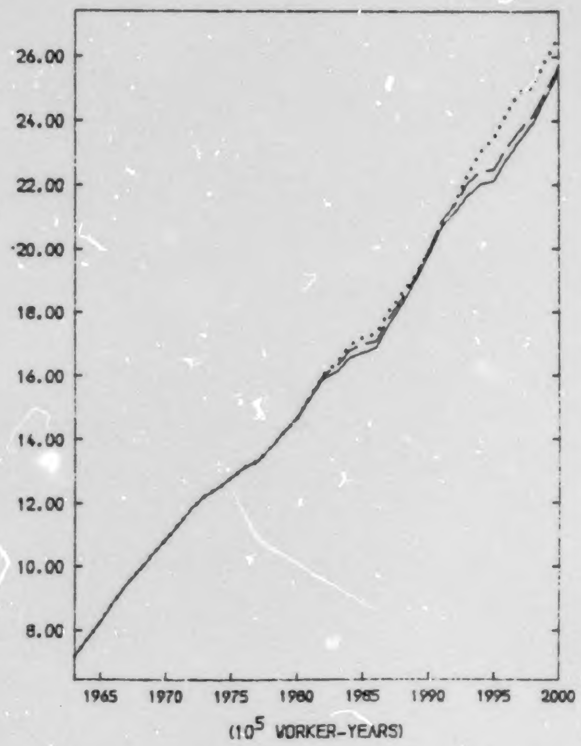
45-TRUCK DRIVERS



46-OTHER OPERATIVES

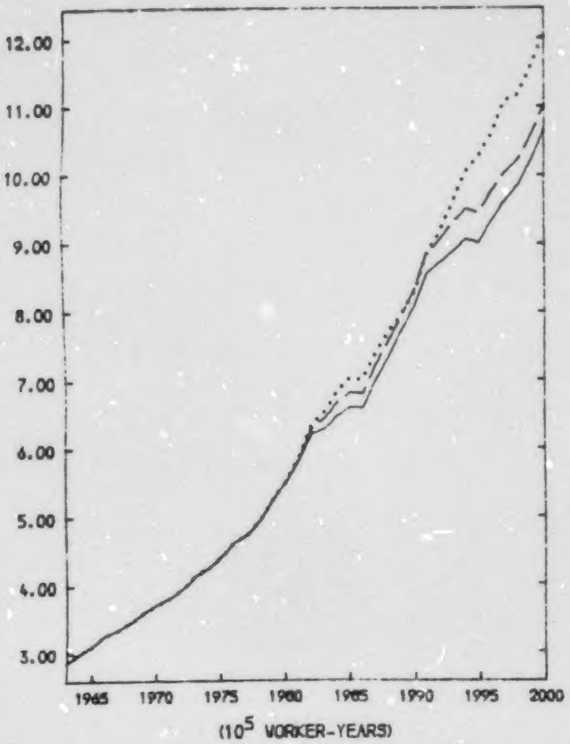


47-ROBOT TECHNICIANS

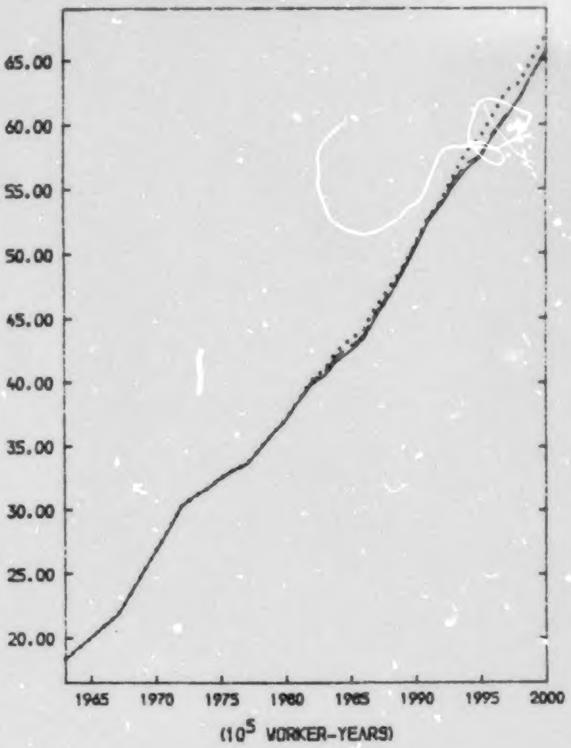


48-JANITORS, SEXTONS

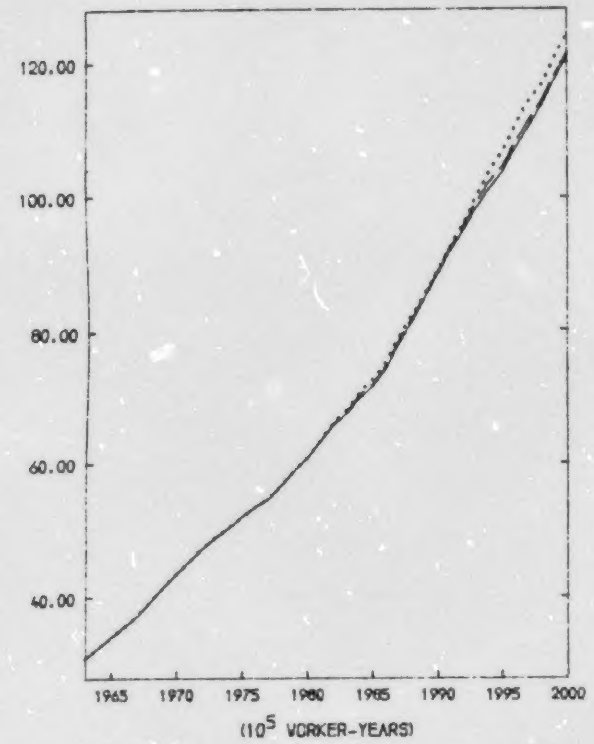
A. EMPLOYMENT BY OCCUPATION



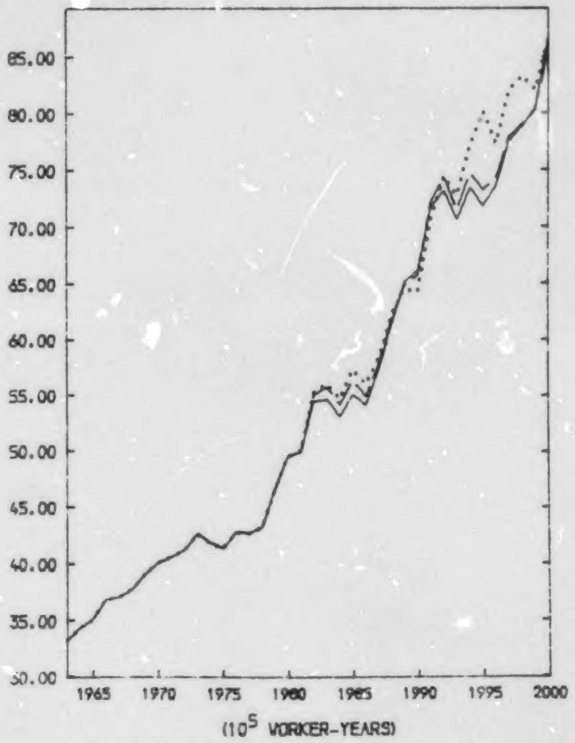
49-PROTECTIVE SERVICE WORKERS



50-FOOD SERVICE

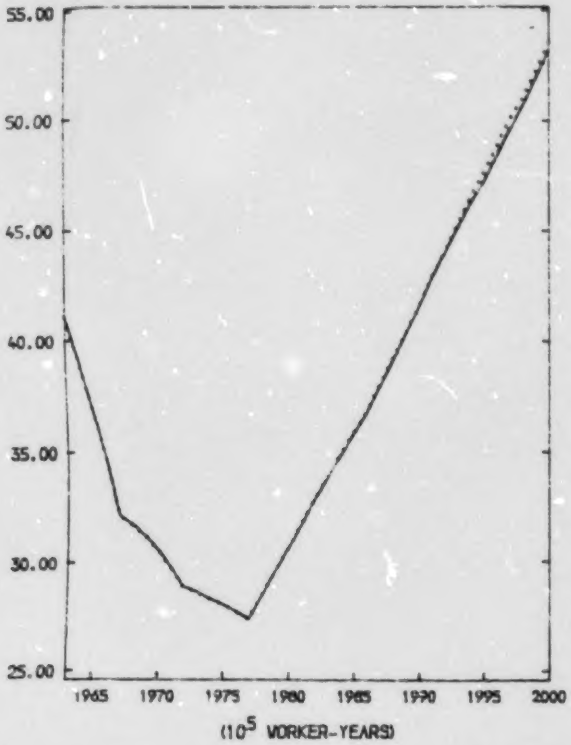


51-OTHER SERVICE

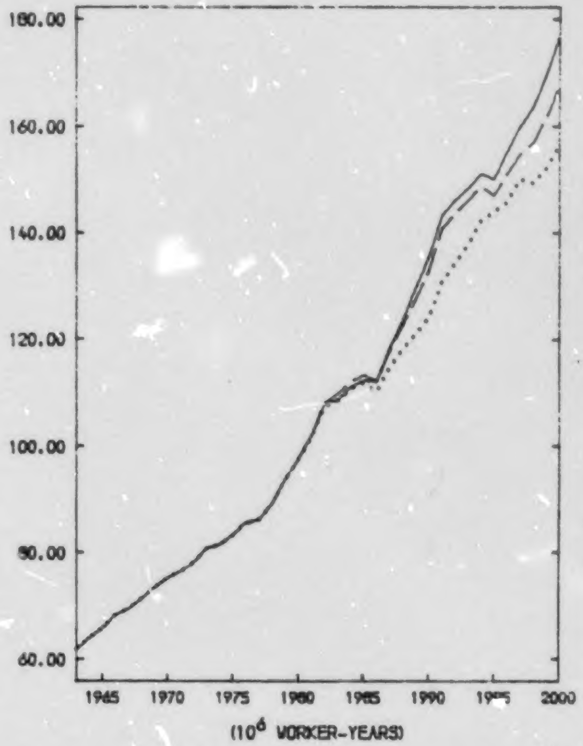


52-LABORERS

A. EMPLOYMENT BY OCCUPATION

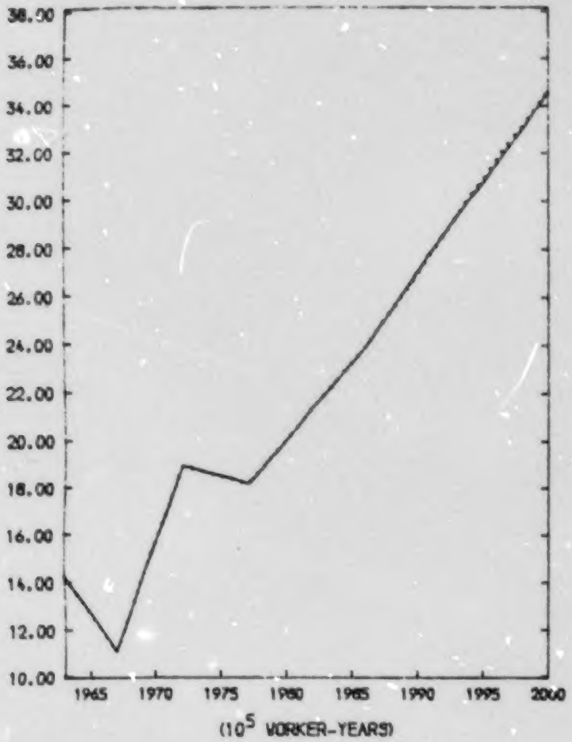


53-FARMERS, FARM WORKERS

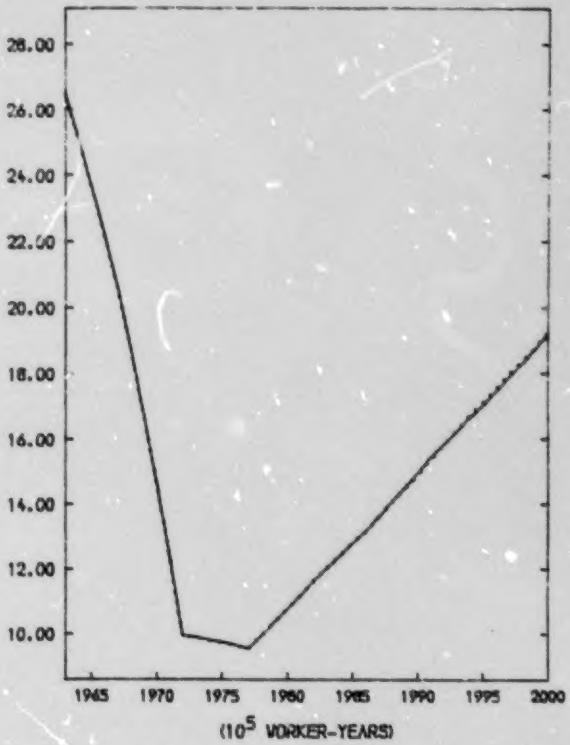


54-TOTAL

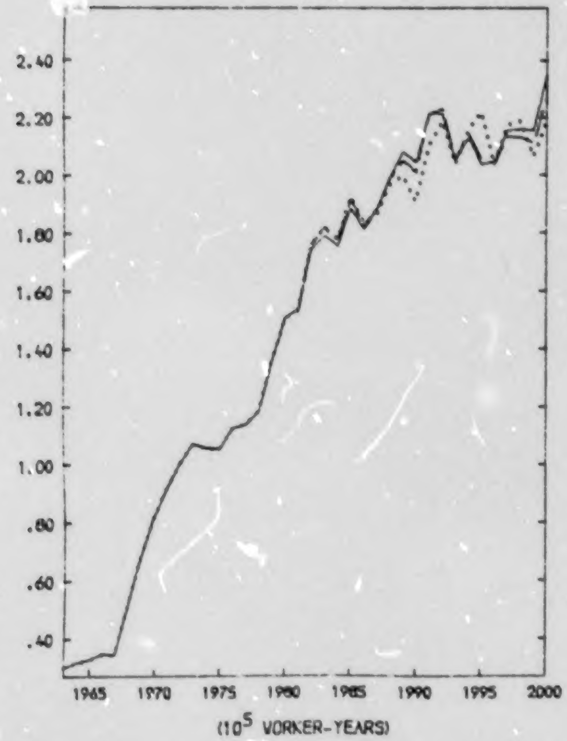
B. EMPLOYMENT BY SECTOR



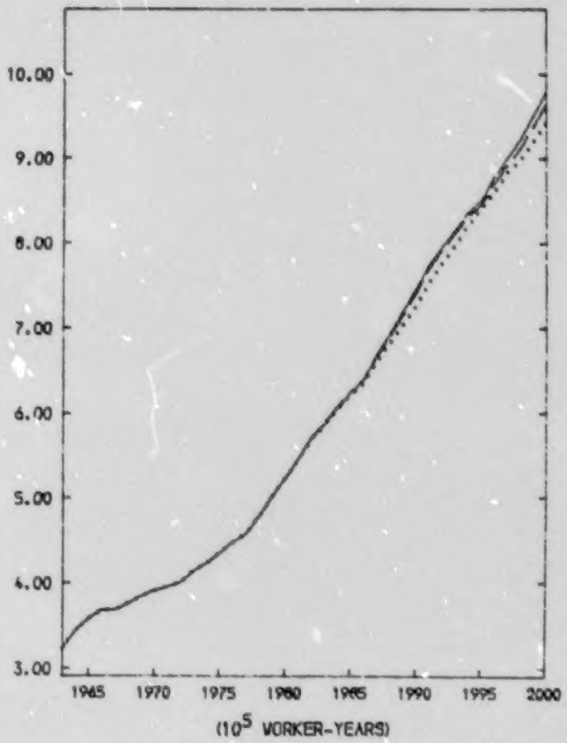
1-LIVESTOCK AND LIVESTOCK PRODUCTS



2-OTHER AGRICULTURAL PRODUCTS

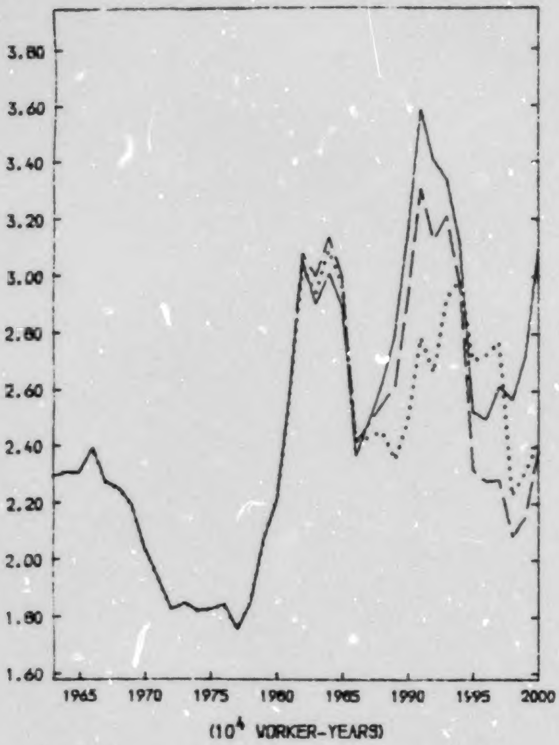


3-FORESTRY AND FISHERY PRODUCTS

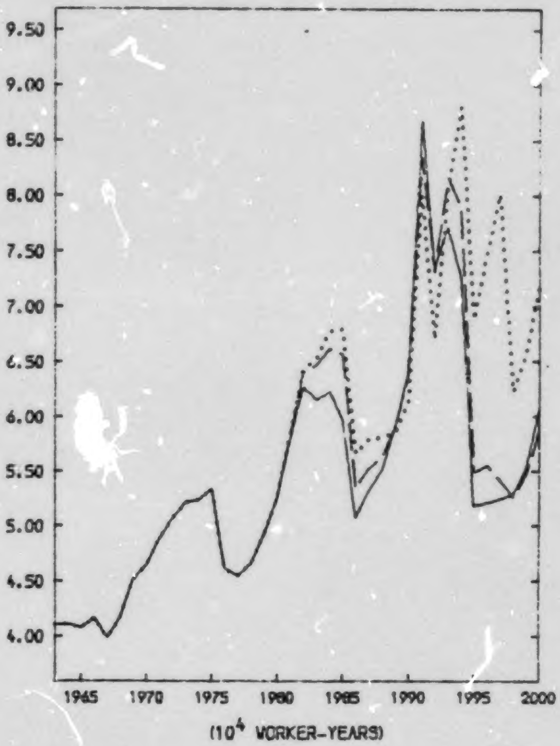


4-AGR. FORESTRY, AND FISHERY SERVICES

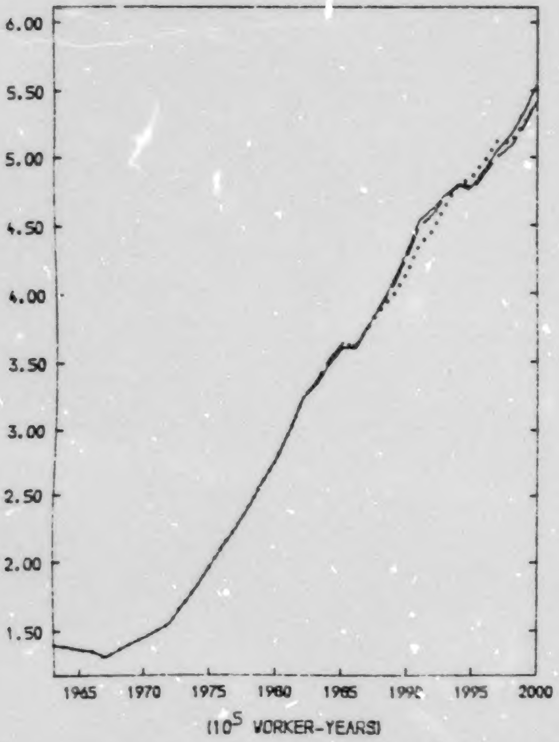
B. EMPLOYMENT BY SECTOR



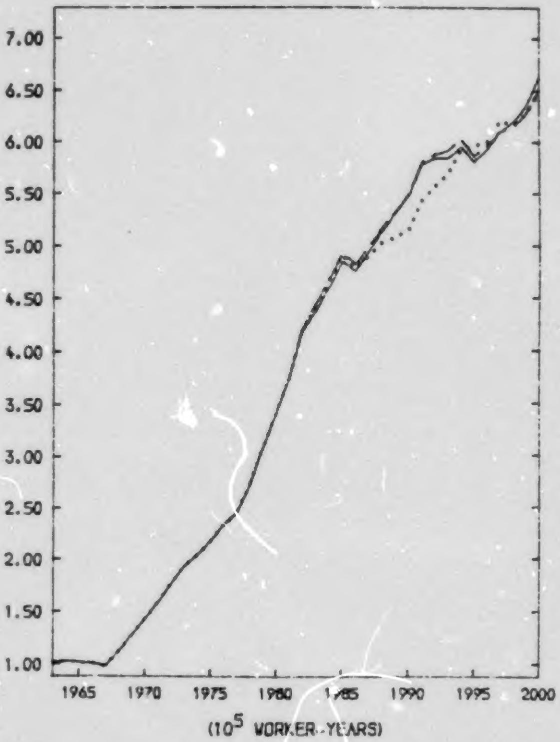
5-IRON AND FERROALLOY ORES MINING



6-NONFERROUS METAL ORES MINING

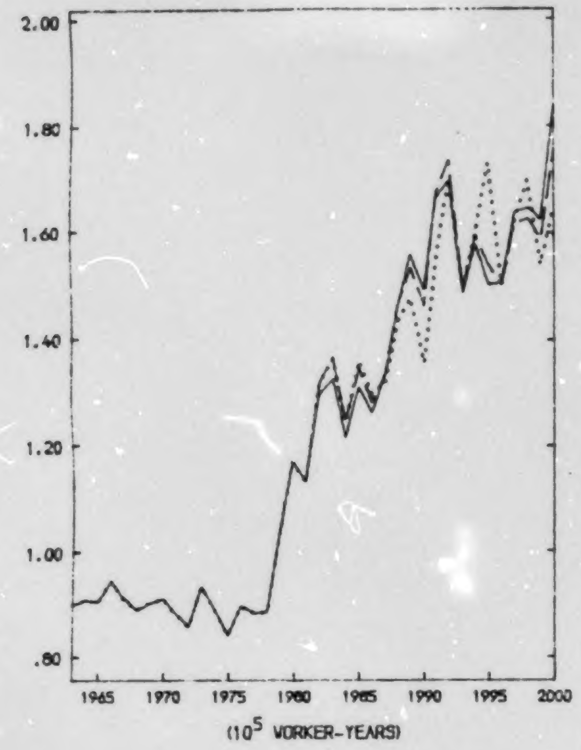


7-COAL MINING

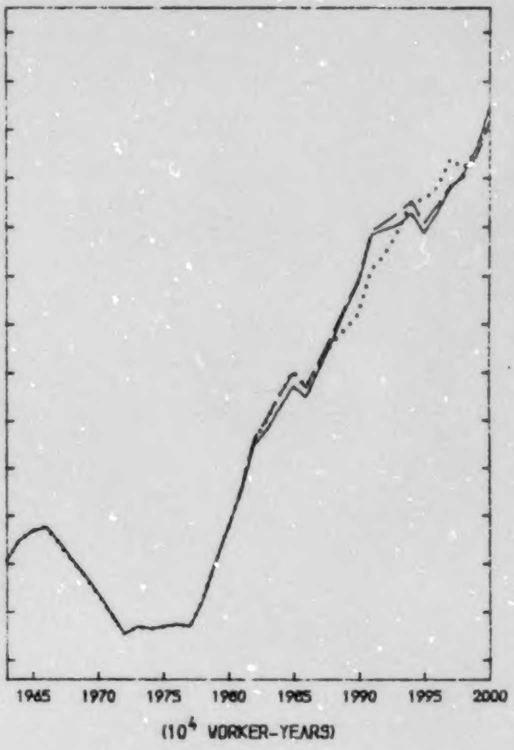


8-CRUDE PETROLEUM AND NATURAL GAS

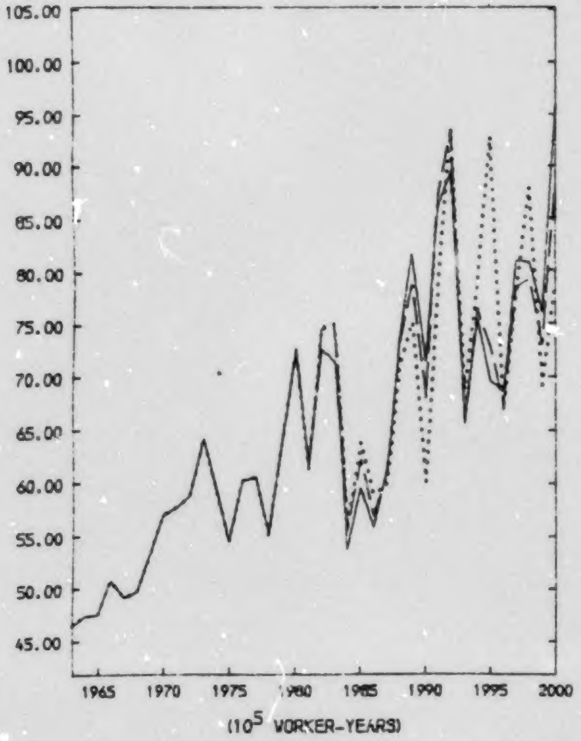
B. EMPLOYMENT BY SECTOR



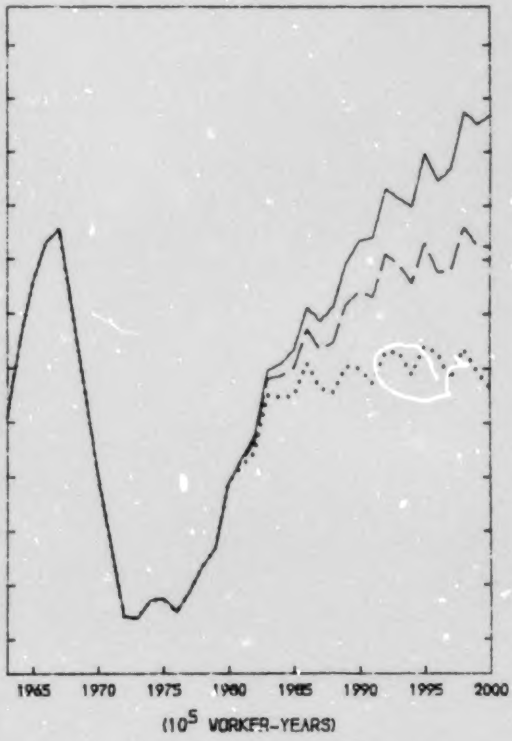
9-STONE AND CLAY MINING AND QUARRYING



10-CHEM AND FERTILIZER MINERAL MINING

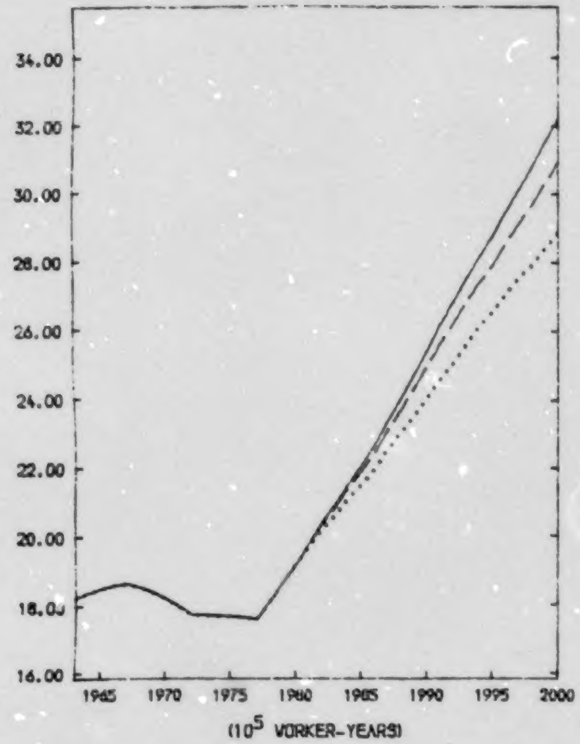


11-CONSTRUCTION

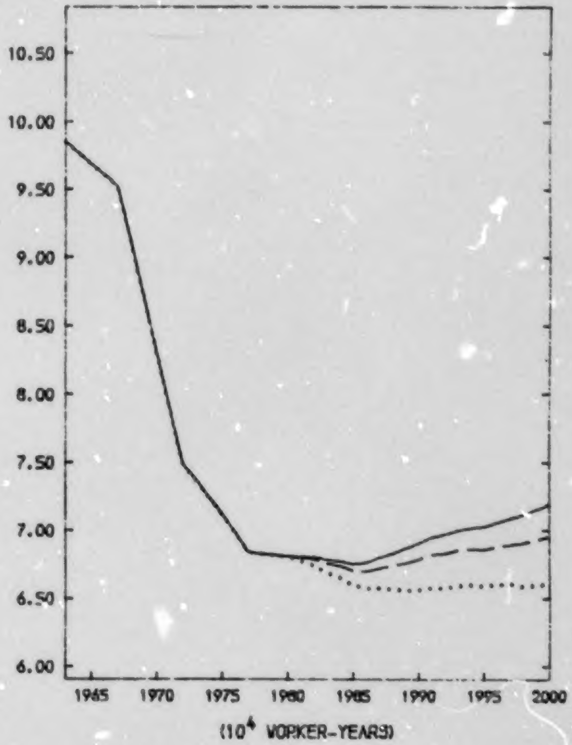


12-ORDNANCE AND ACCESSORIES

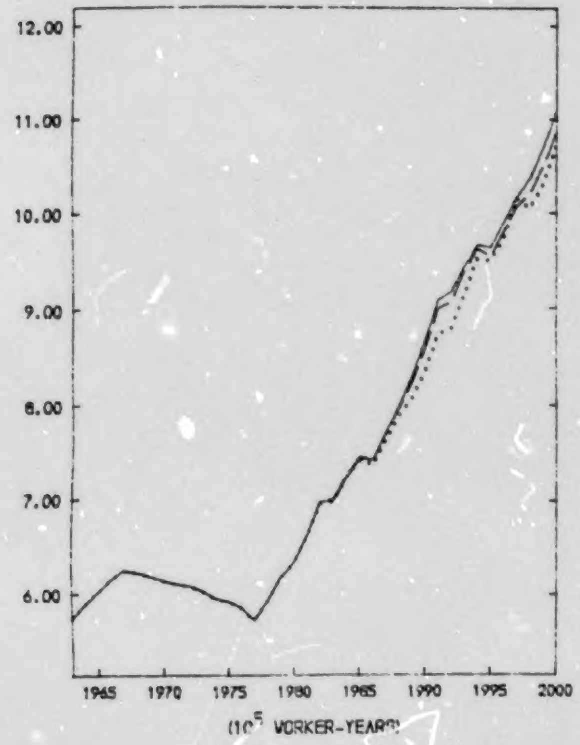
B. EMPLOYMENT BY SECTOR



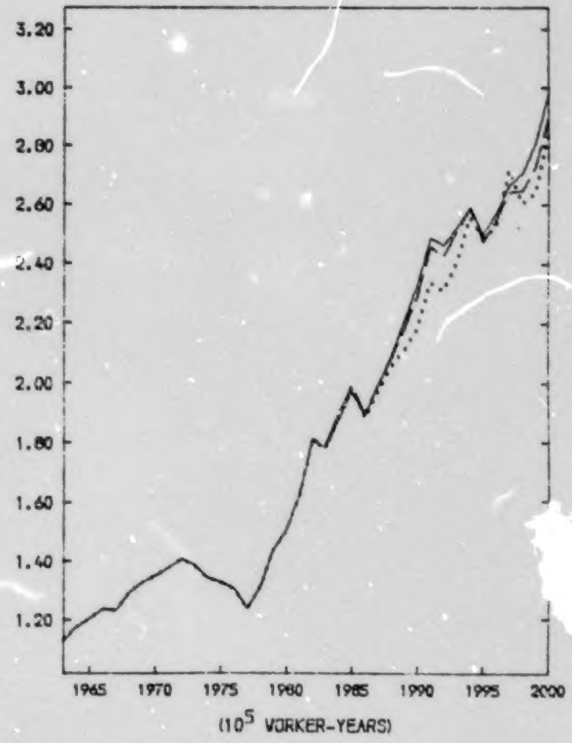
13-FOOD AND KINDRED PRODUCTS



14-TOBACCO

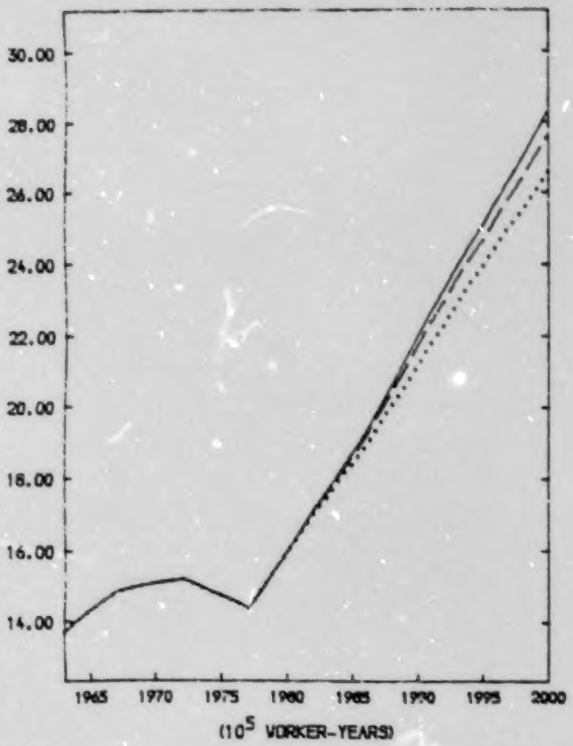


15-FABRICS, YARN AND THREAD MILLS

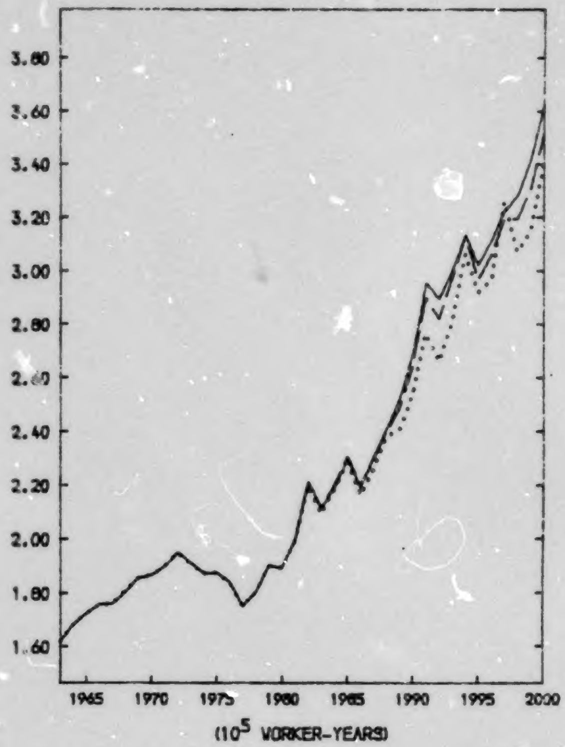


16-MISC TEXTILE GOODS AND FLOOR COVERING

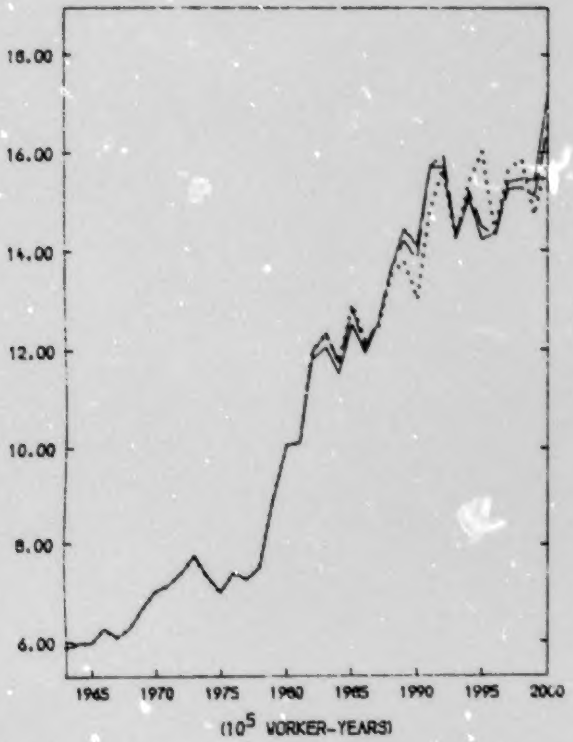
B. EMPLOYMENT BY SECTOR



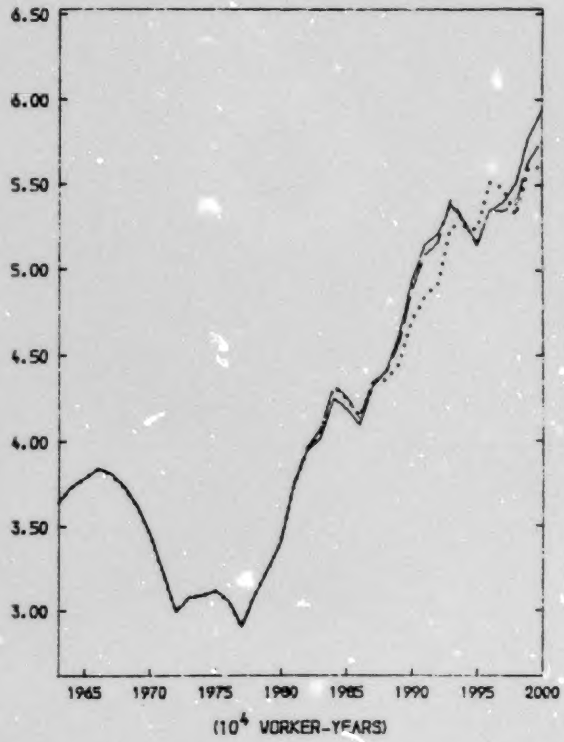
17-APPAREL



18-MISC FABRICATED TEXTILE PRODUCTS

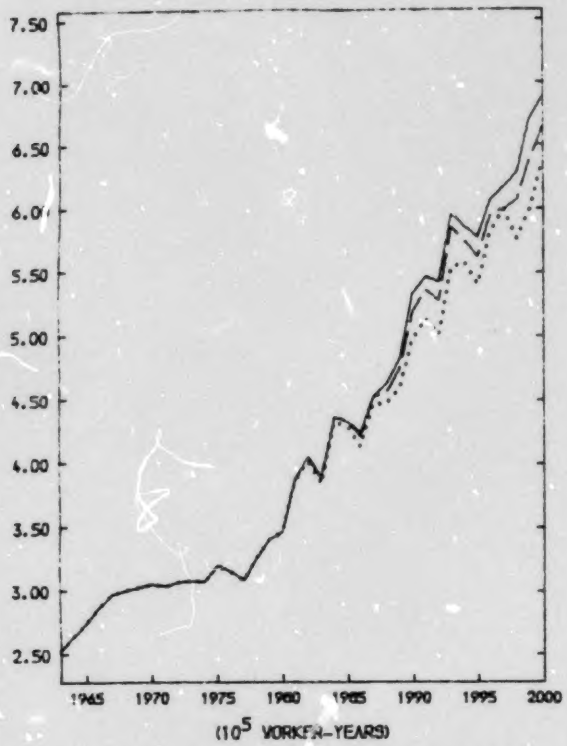


19-LUMBER AND WOOD PROD, EXC CONTAINERS

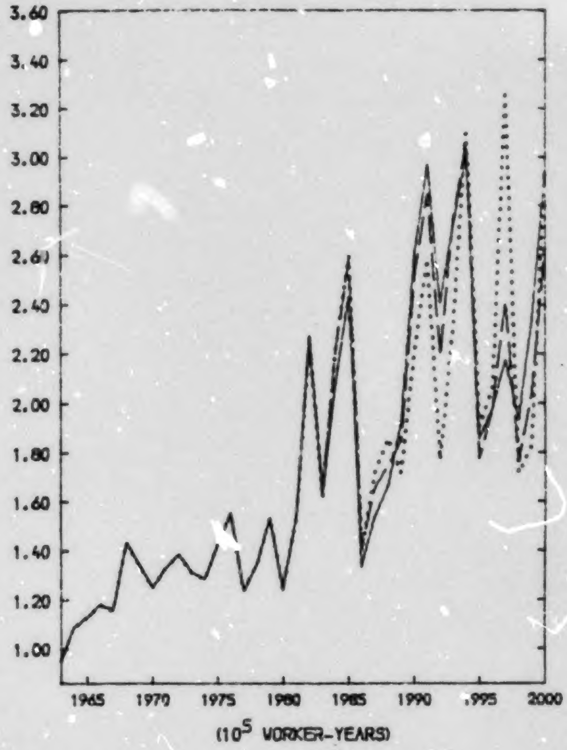


20-WOOD CONTAINERS

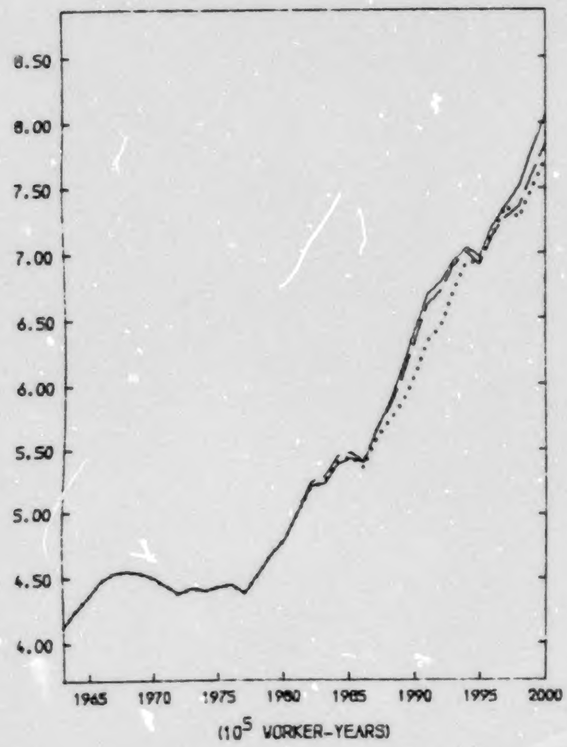
B. EMPLOYMENT BY SECTOR



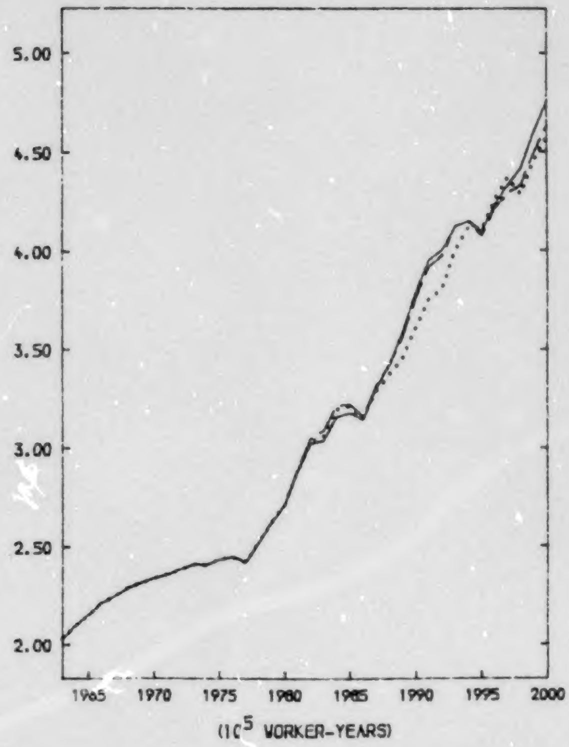
21-HOUSEHOLD FURNITURE



22-OTHER FURNITURE AND FIXTURES

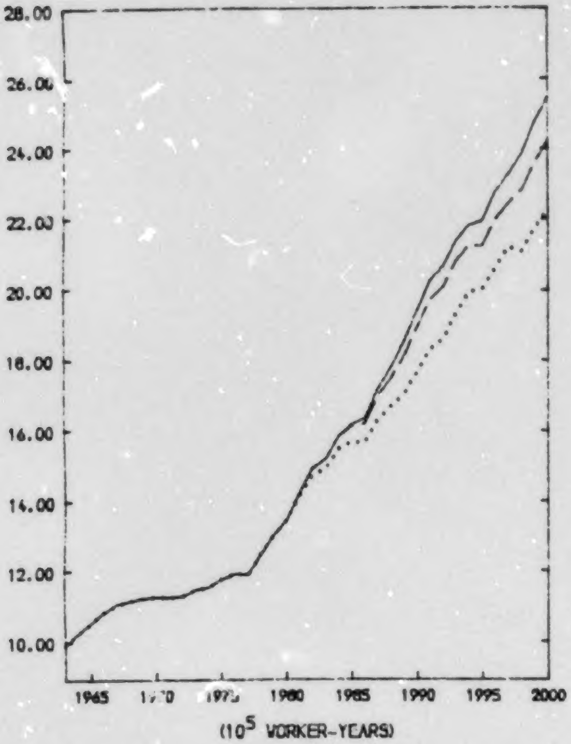


23-PAPER AND ALLIED PROD. EXC CONTAINERS

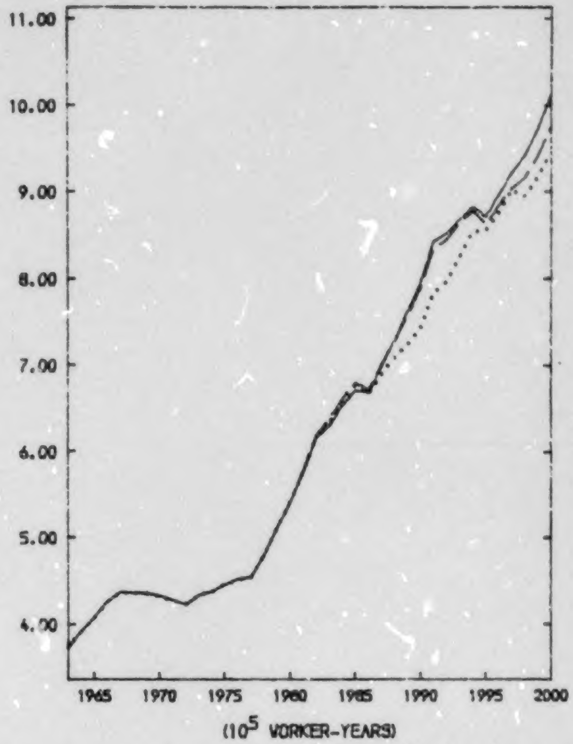


24-PAPERBOARD CONTAINERS AND BOXES

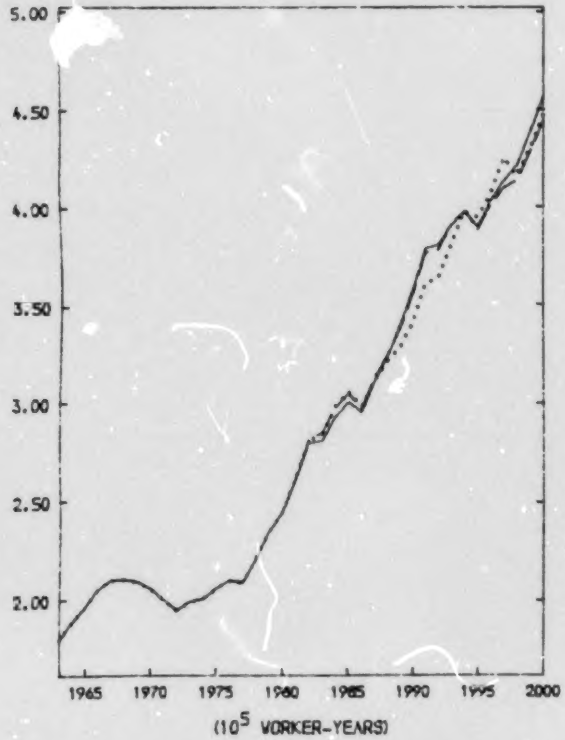
B. EMPLOYMENT BY SECTOR



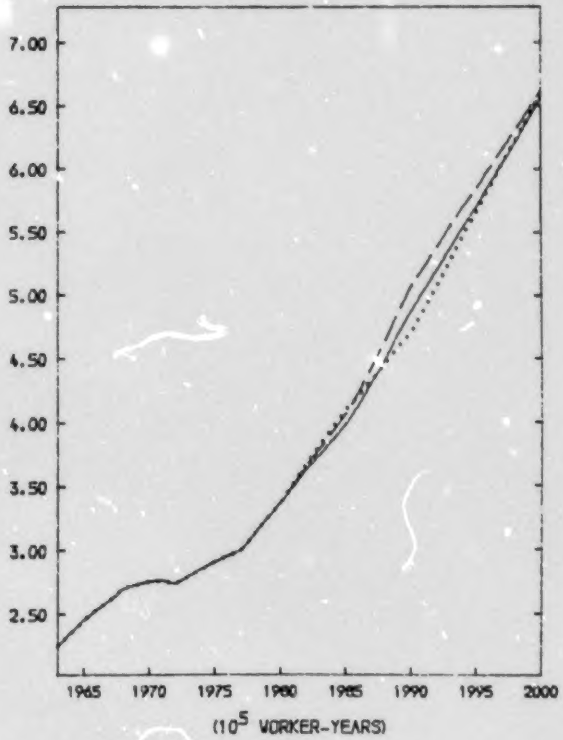
25-PRINTING AND PUBLISHING



26-CHEMICALS AND SELECTED CHEM PRODUCTS

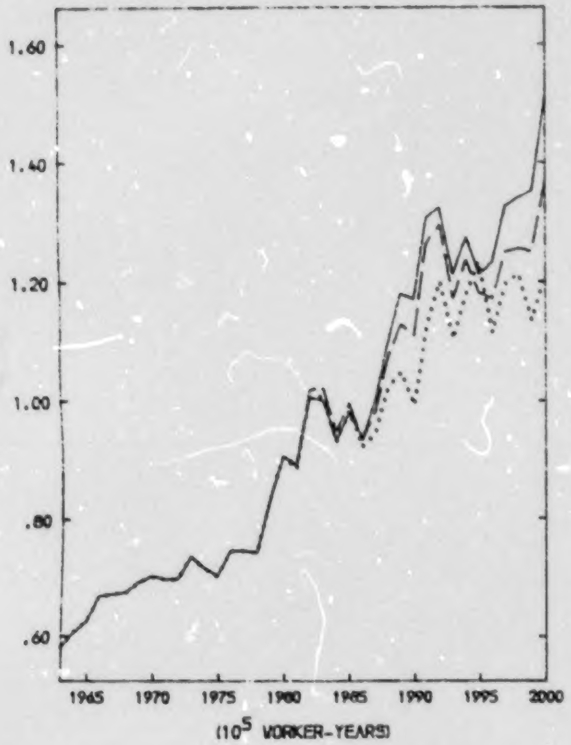


27-PLASTICS AND SYNTHETIC MATERIALS

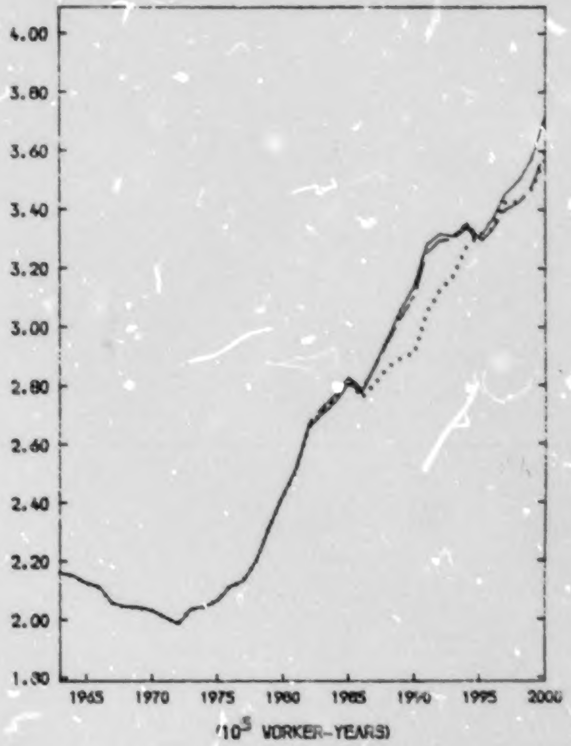


28-DRUGS, CLEANING AND TOILET PREPARATION

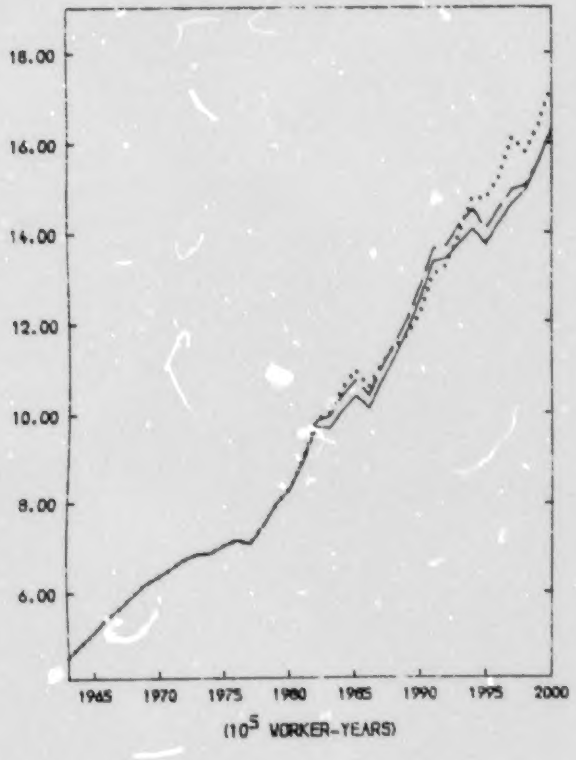
B. EMPLOYMENT BY SECTOR



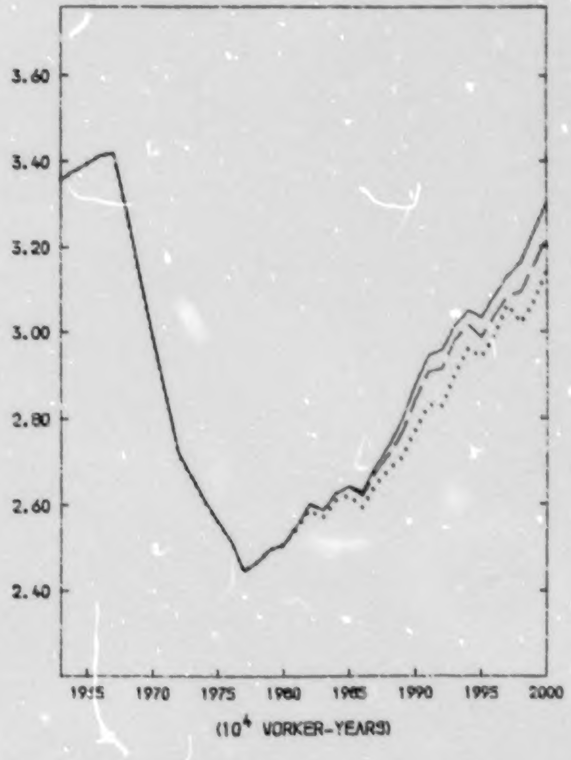
29-PAINTS AND ALLIED PRODUCTS



30-PETROLEUM REFINING AND ALLIED IND.

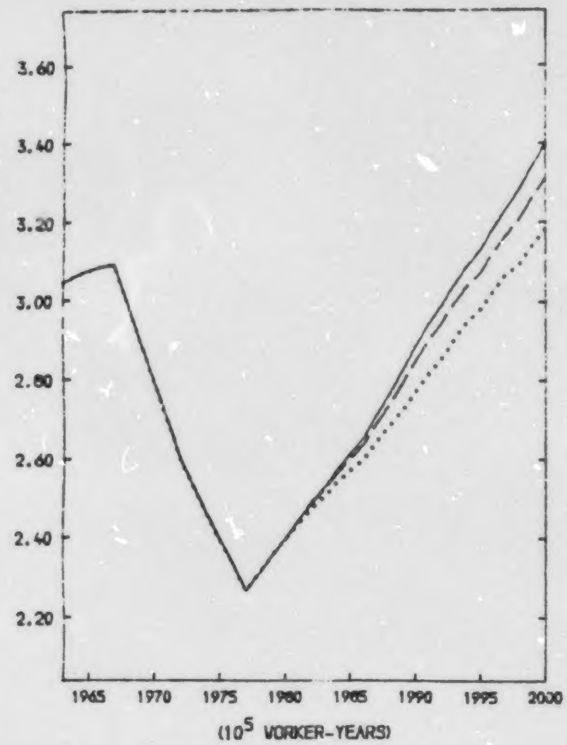


31-RUBBER AND MISC PLASTIC PRODUCTS

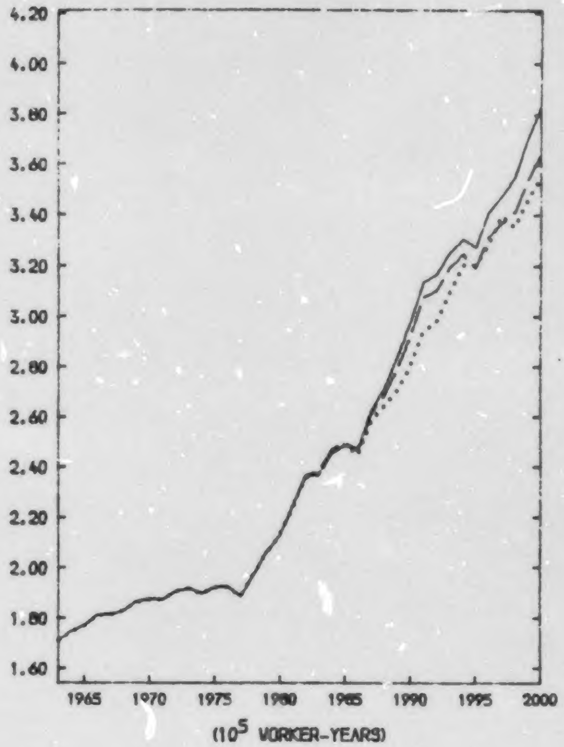


32-LEATHER TANNING AND FINISHING

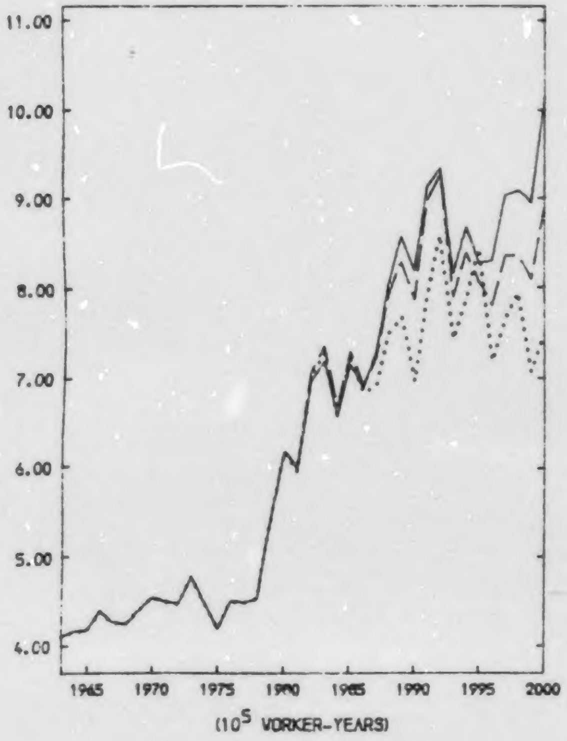
B. EMPLOYMENT BY SECTOR



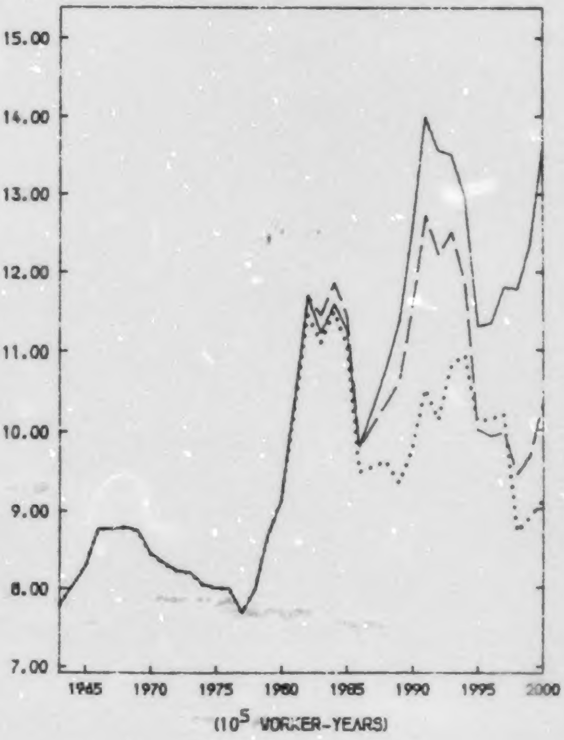
33-FOOTWEAR AND OTHER LEATHER PRODUCTS



34-GLASS AND GLASS PRODUCTS

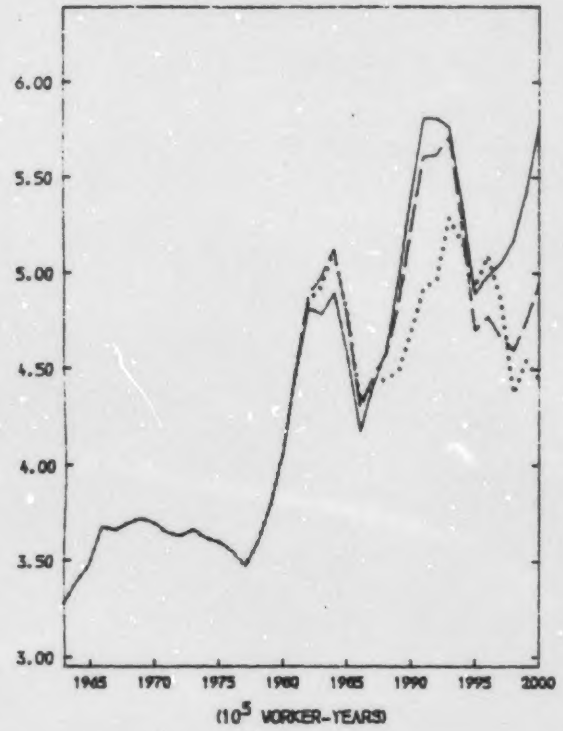


35-STONE AND CLAY PRODUCTS

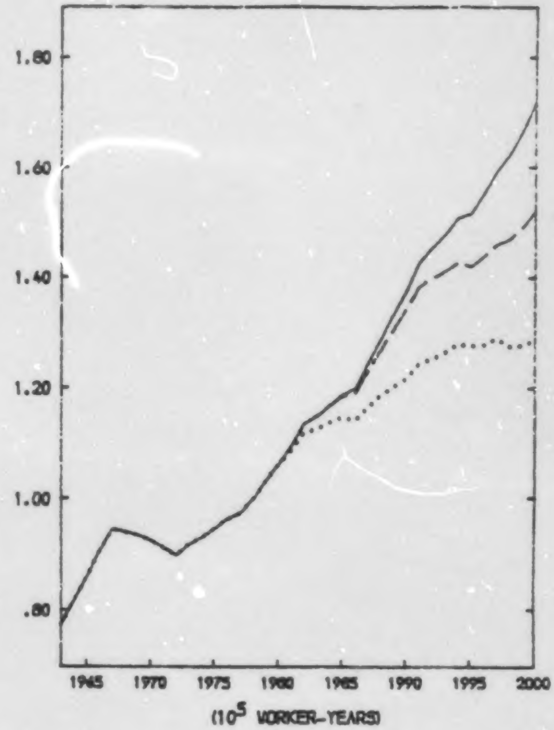


36-PRIMARY IRON AND STEEL MANUFACTURING

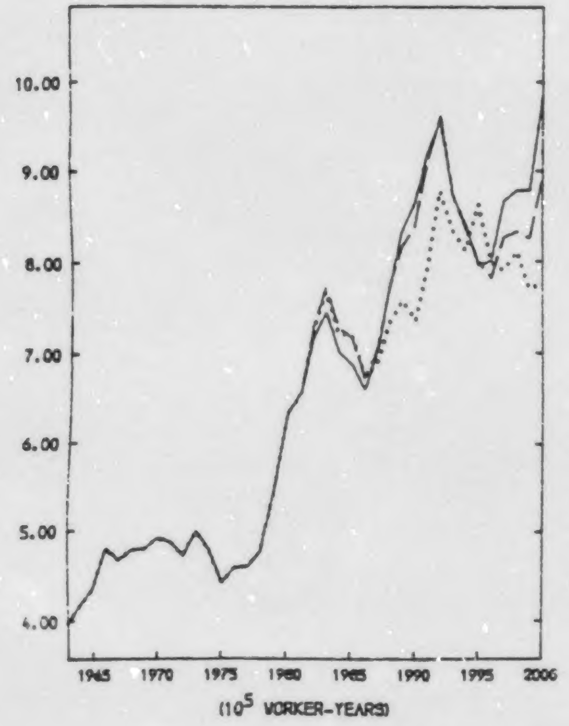
B. EMPLOYMENT BY SECTOR



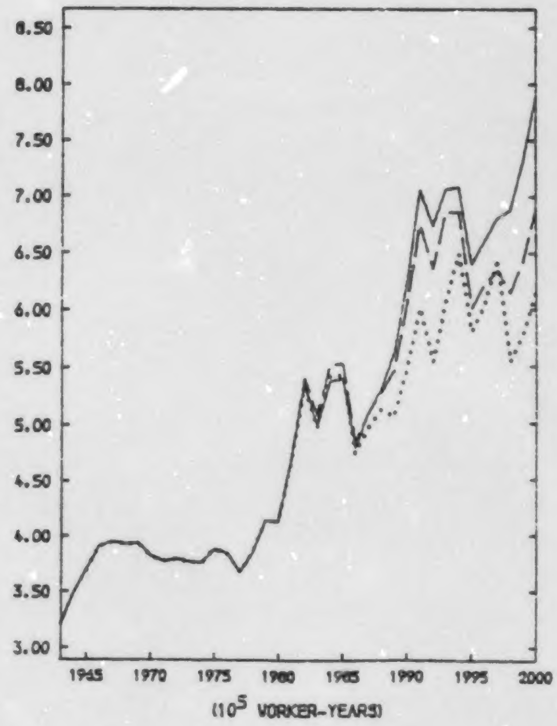
37-PRIMARY NONFERROUS METALS MANUFACTURE



38-METAL CONTAINERS

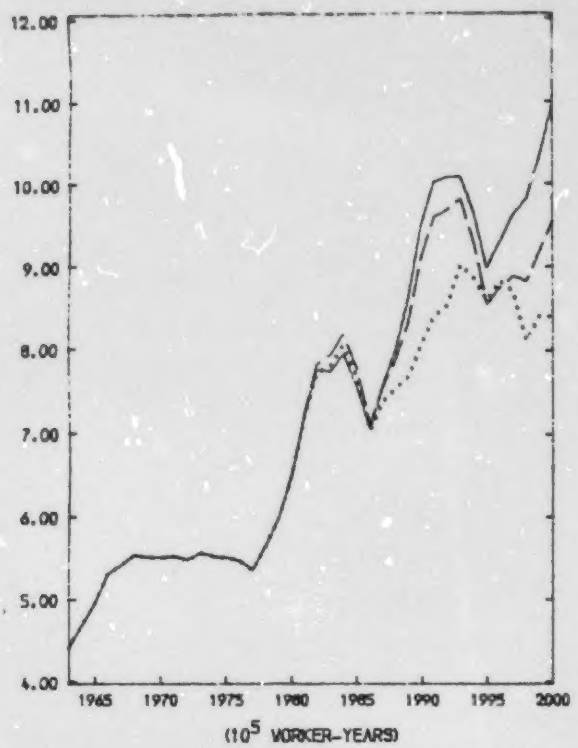


39-HEATING, PLUMBING, OTHER METAL PRODUCTS

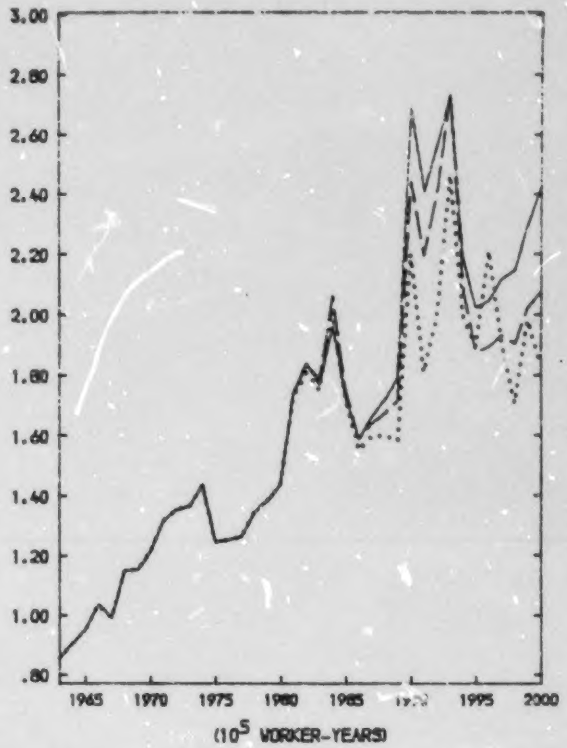


40-SCREW MACHINE PRODUCTS AND STAMPINGS

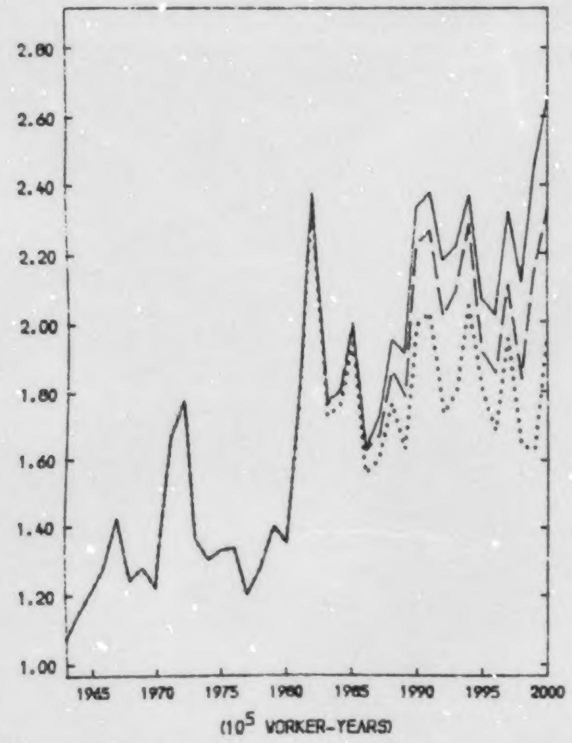
B. EMPLOYMENT BY SECTOR



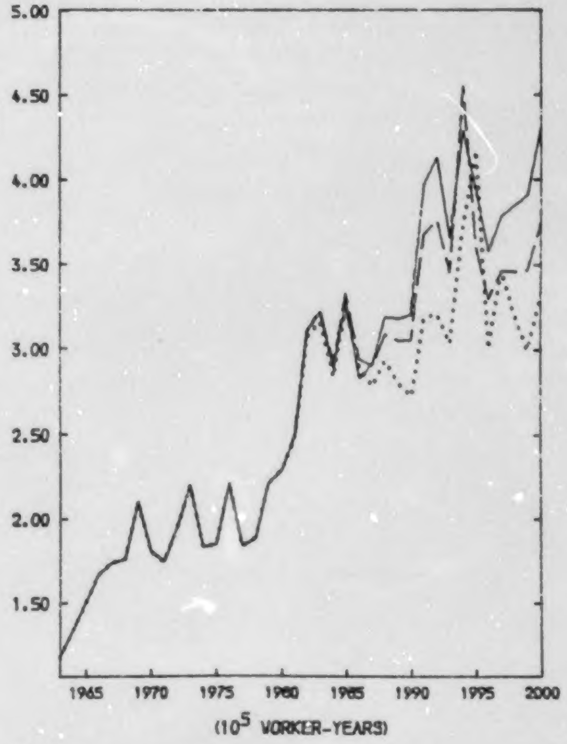
41-OTHER FABRICATED METAL PRODUCTS



42-ENGINES AND TURBINES

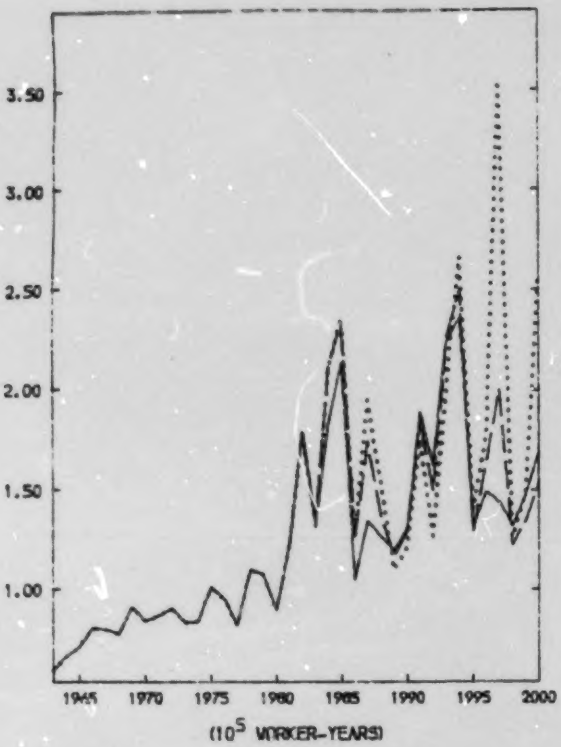


43-FARM AND GARDEN MACHINERY

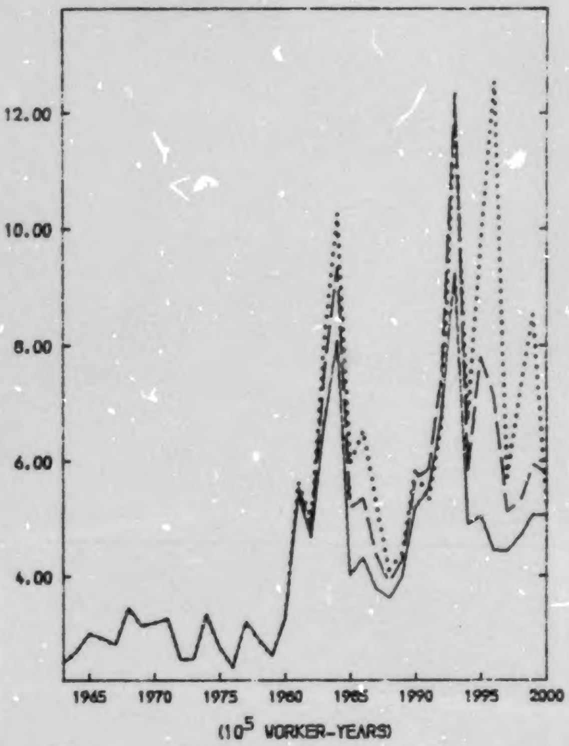


44-CONSTRUCTION AND MINING MACHINERY

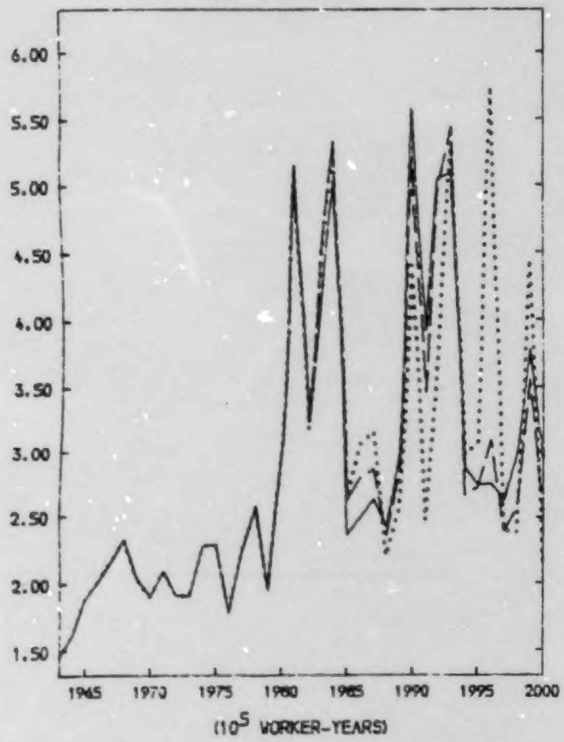
B. EMPLOYMENT BY SECTOR



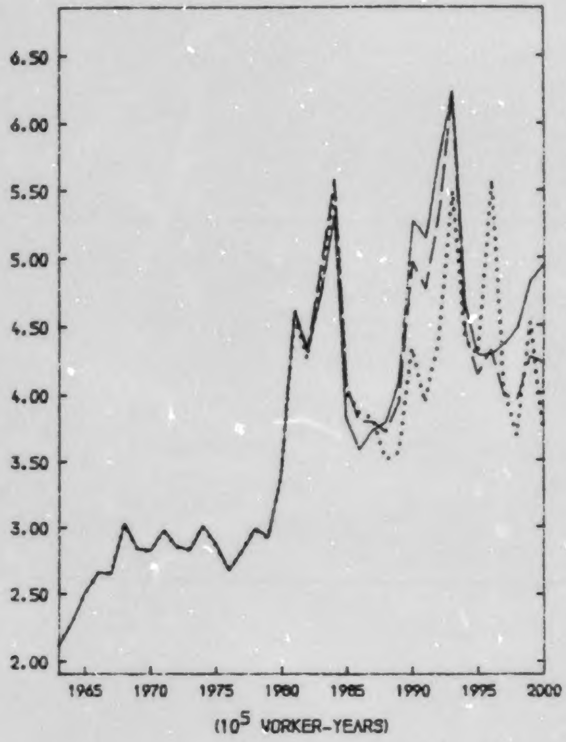
45-MATERIALS HANDLING EQUIPMENT



46-METALWORKING MACHINERY AND EQUIPMENT

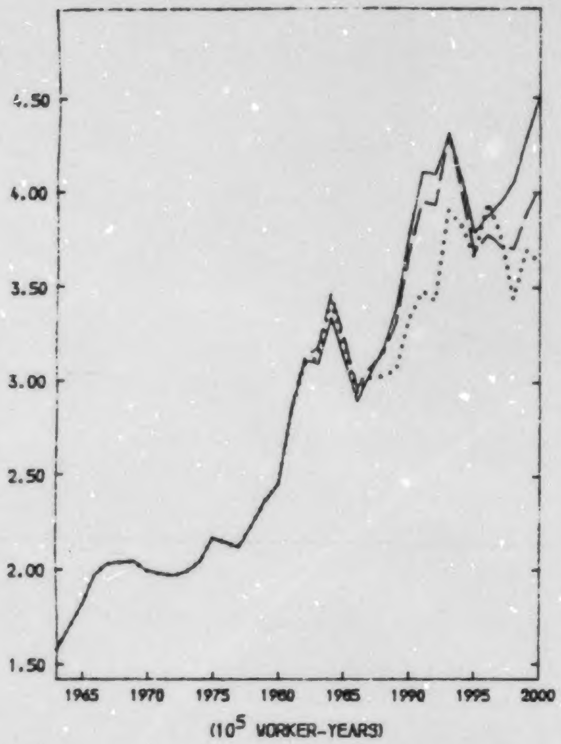


47-SPECIAL INDUSTRY EQUIPMENT

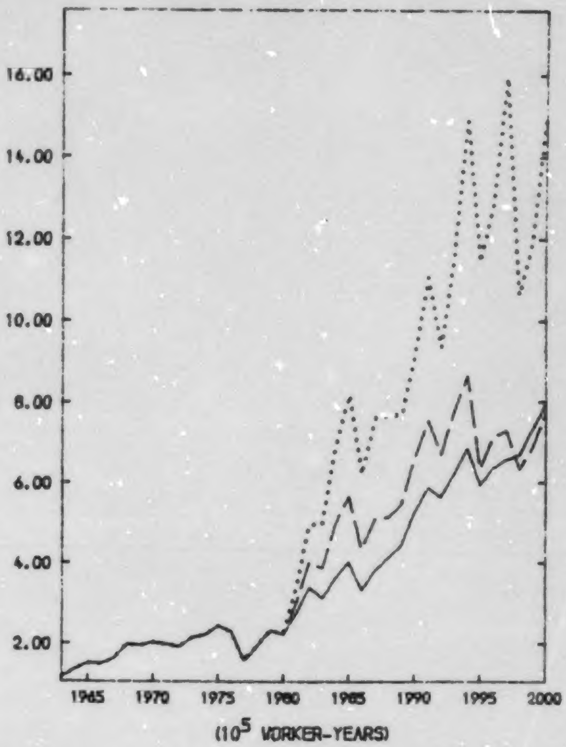


48-GENERAL INDUSTRIAL EQUIPMENT

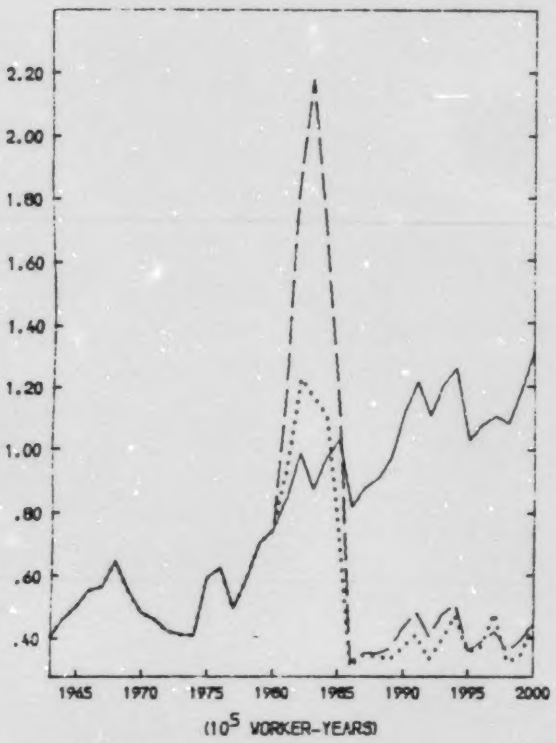
B. EMPLOYMENT BY SECTOR



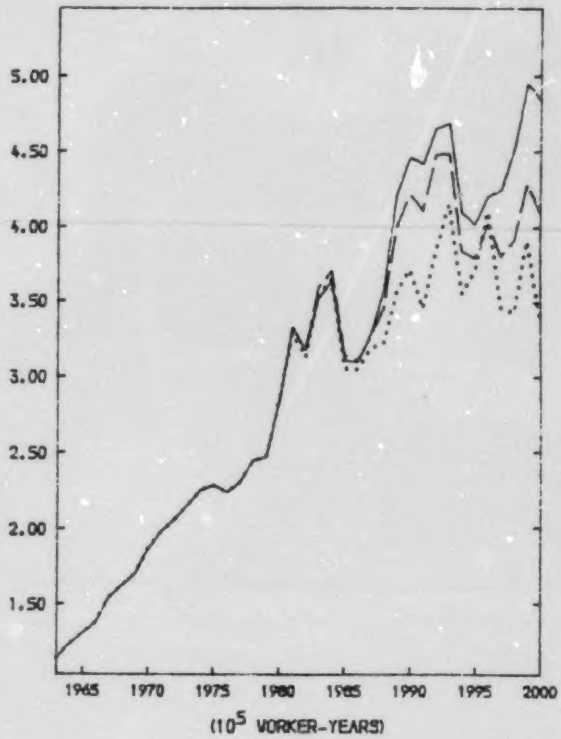
49-MISC MACHINERY, EXCEPT ELECTRICAL



50-ELECTRONIC COMPUTING EQUIPMENT

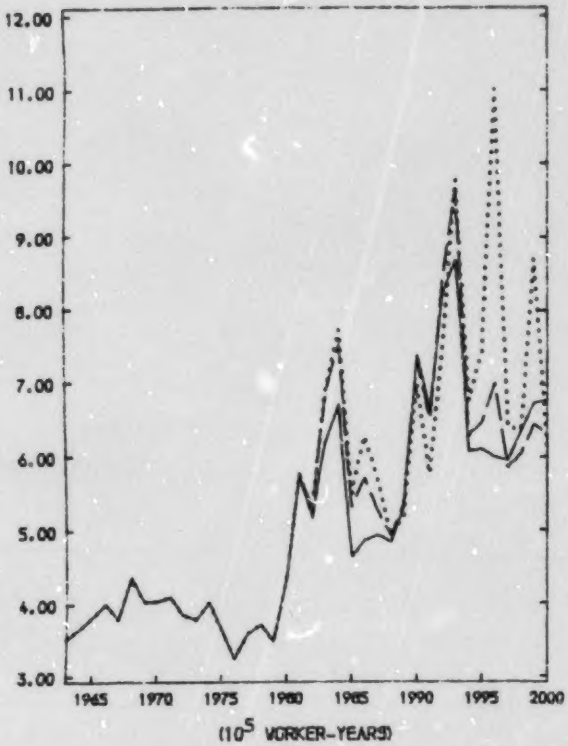


51-OFFICE MACHINES, EXCEPT COMPUTERS

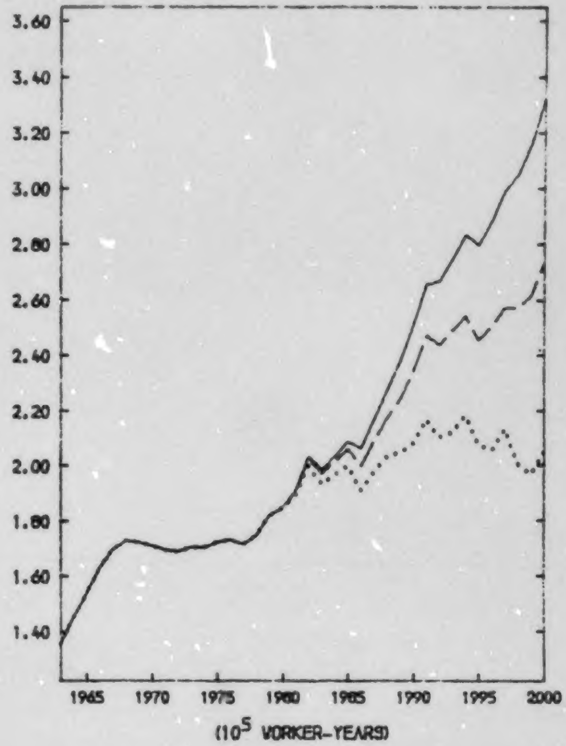


52-SERVICE INDUSTRY MACHINES

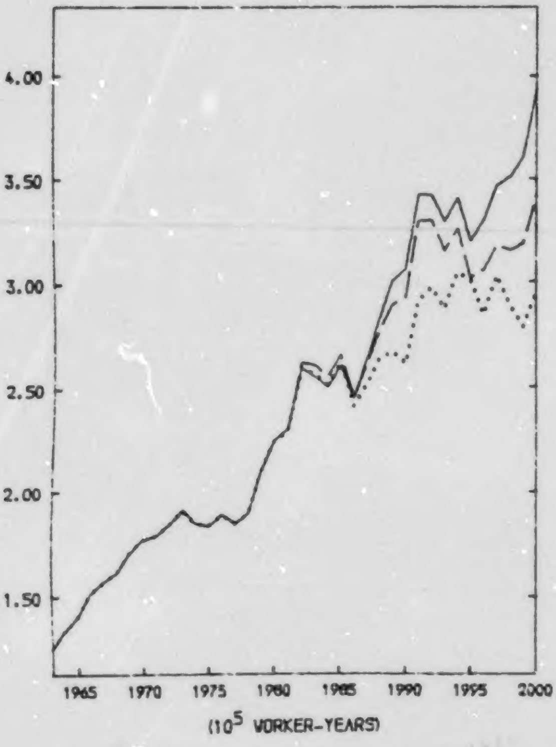
B. EMPLOYMENT BY SECTOR



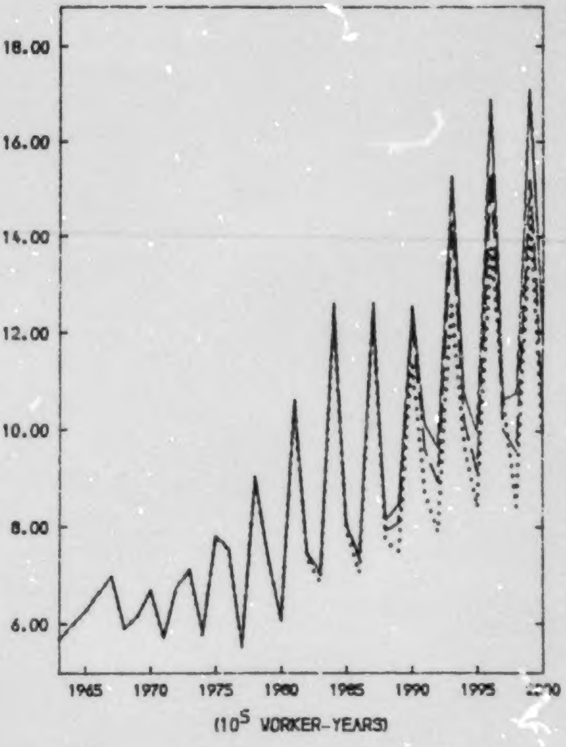
53-ELECTRIC INDUSTRIAL EQUIPMENT



54-HOUSEHOLD APPLIANCES

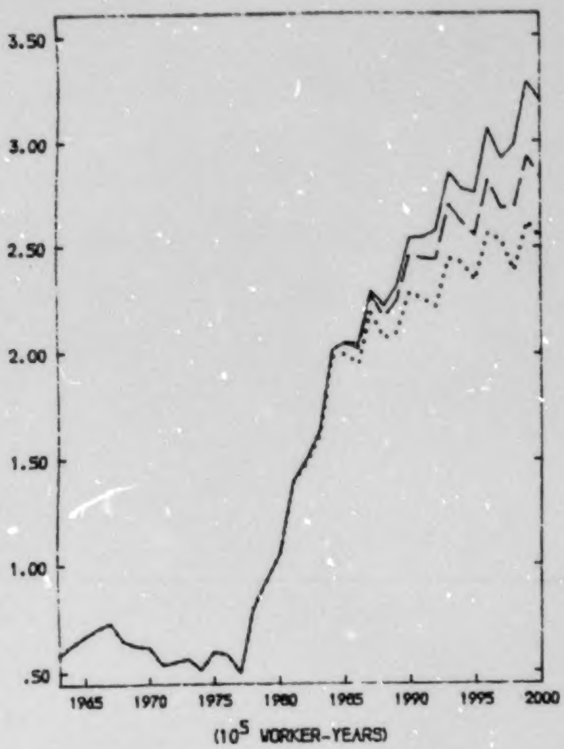


55-ELECTRIC LIGHTING AND WIRING EQUIP.

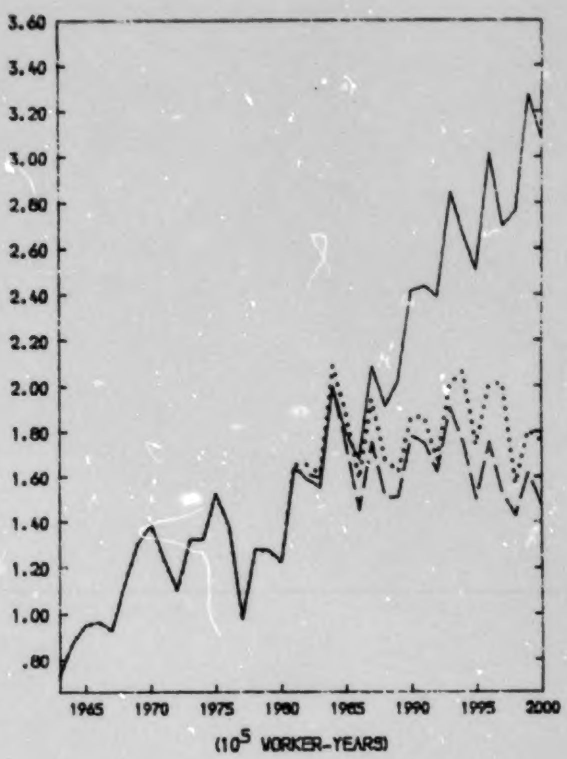


56-RADIO,TV AND COMMUNICATIONS EQUIPMENT

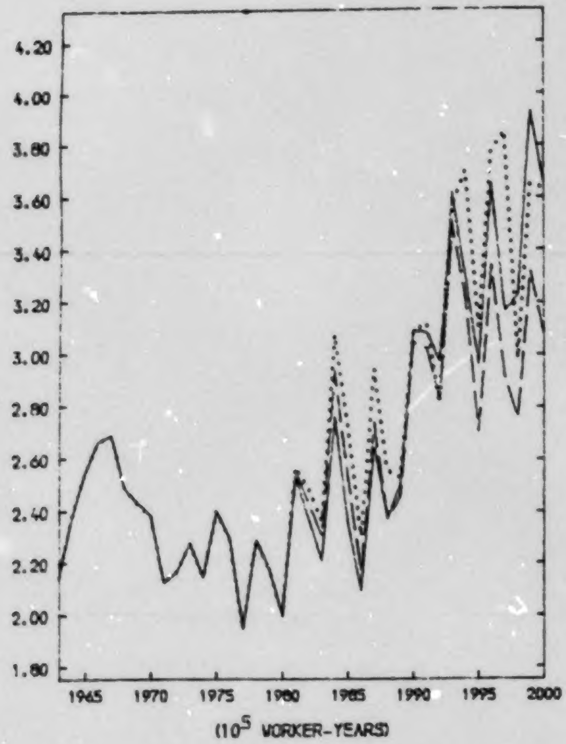
B. EMPLOYMENT BY SECTOR



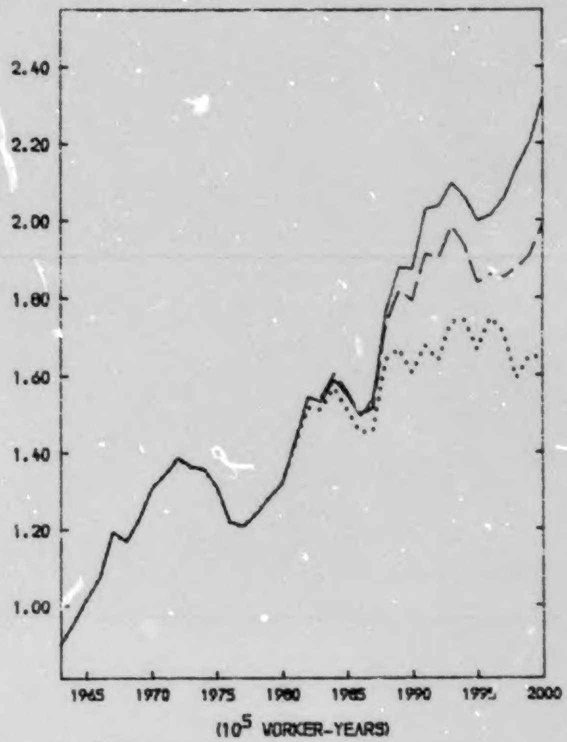
57-ELECTRON TUBES



58-SEMICONDUCTORS AND RELATED DEVICES

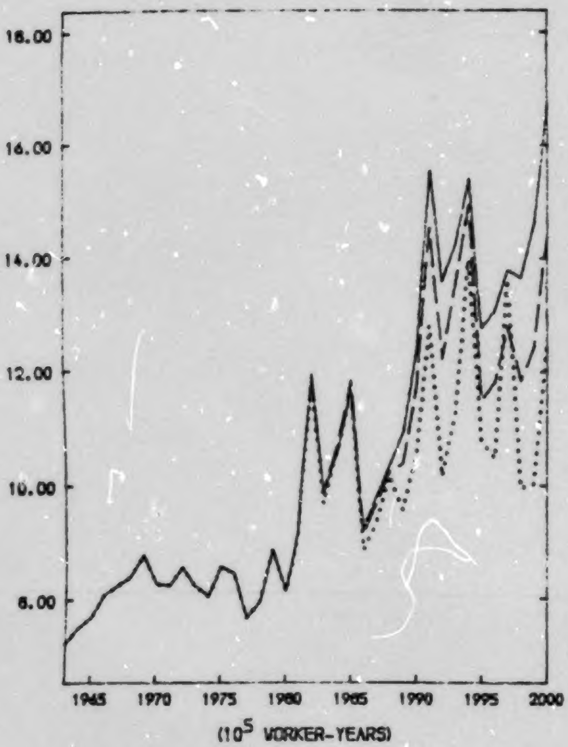


59-ELECTRONIC COMPONENTS, NEC

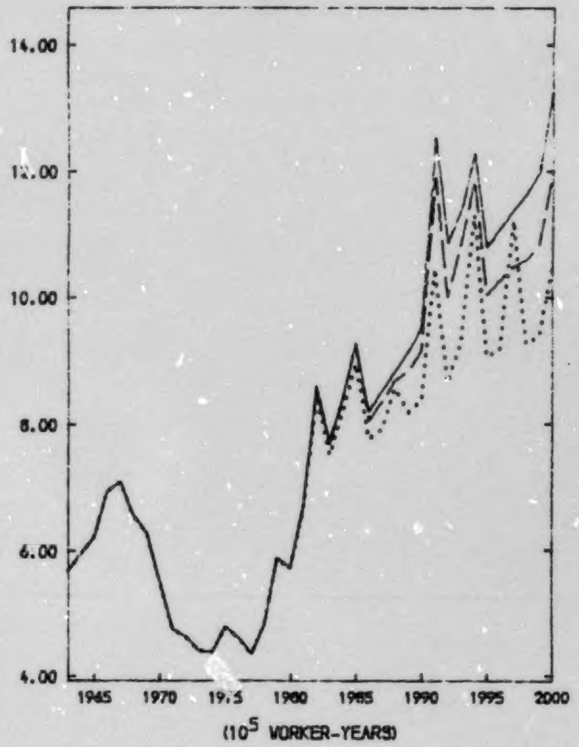


60-MISC ELECTRIC. MACHINERY AND SUPPLIES

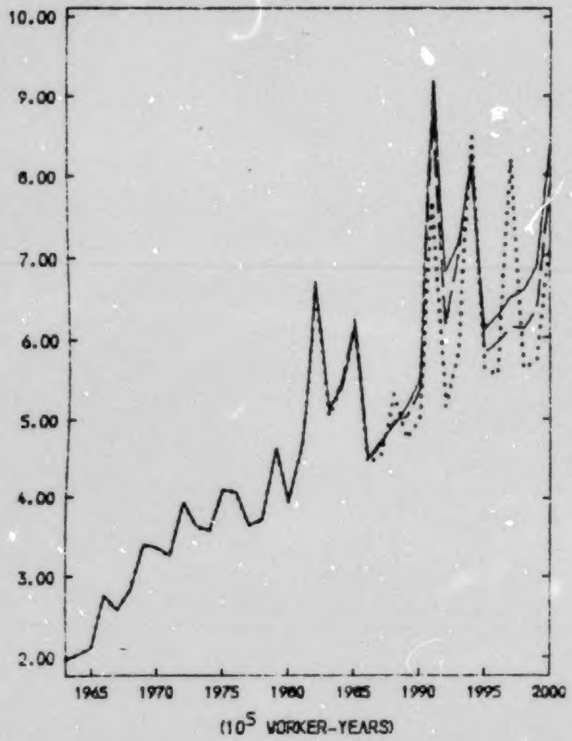
B. EMPLOYMENT BY SECTOR



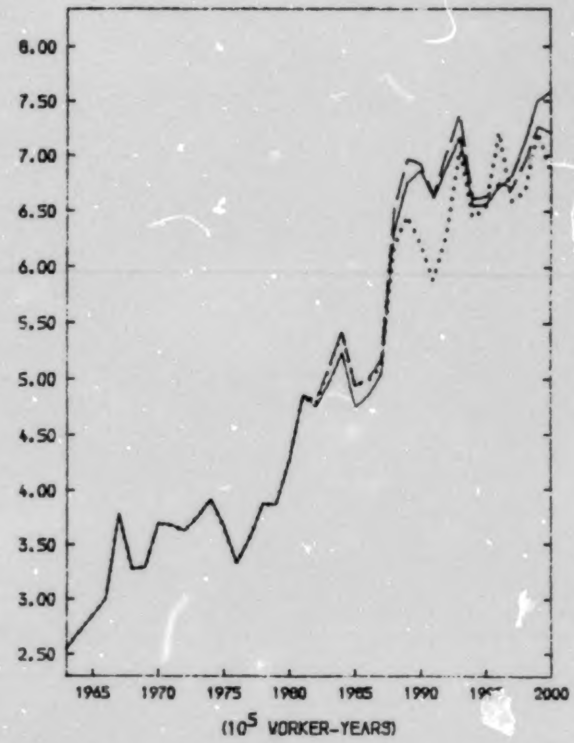
61-MOTOR VEHICLES AND EQUIPMENT



62-AIRCRAFT AND PARTS

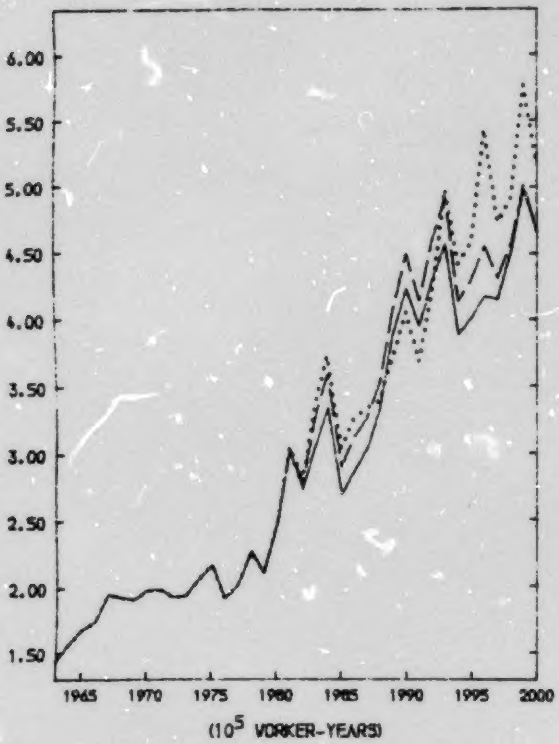


63-OTHER TRANSPORTATION EQUIPMENT

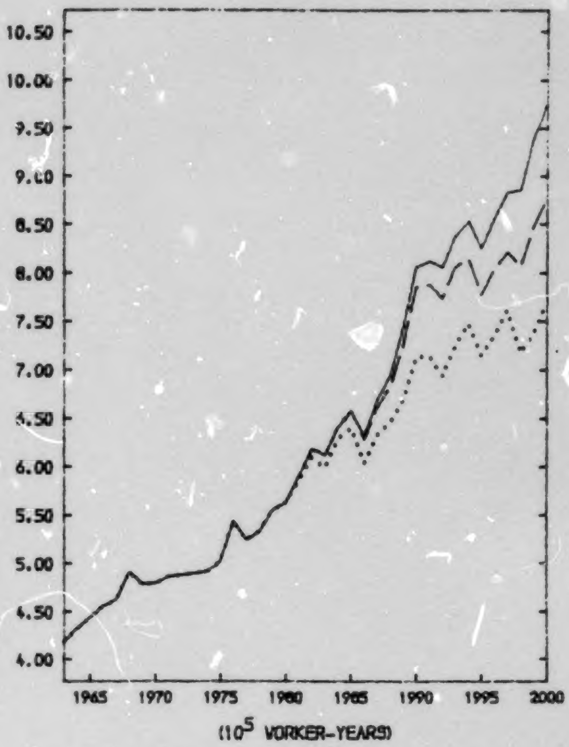


64-SCIENTIFIC AND CONTROL INSTRUMENTS

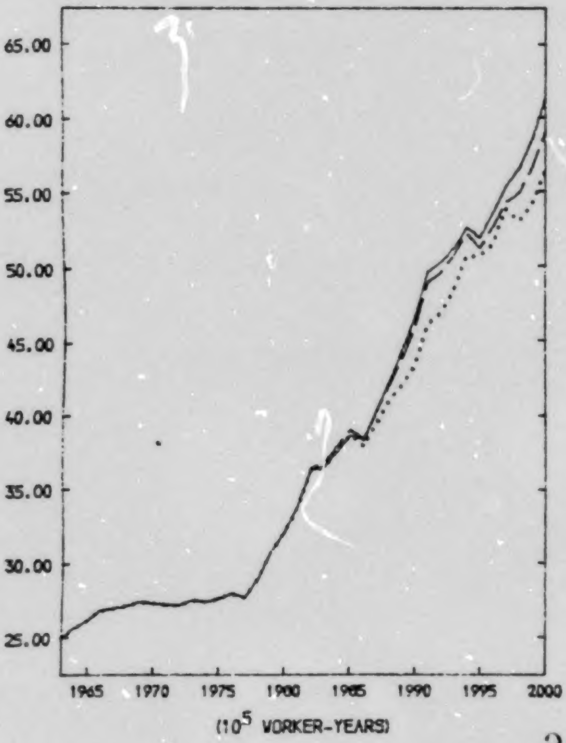
B. EMPLOYMENT BY SECTOR

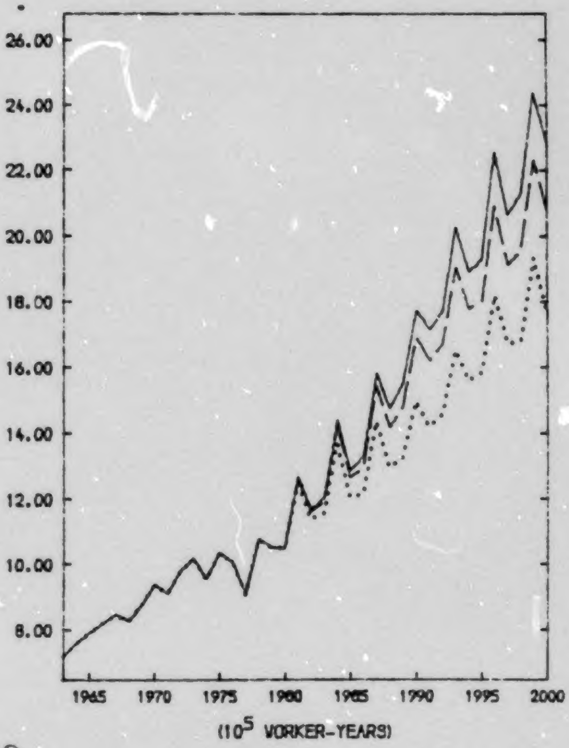


65-OPTICAL AND PHOTOGRAPHIC EQUIPMENT



66-MISCELLANEOUS MANUFACTURING





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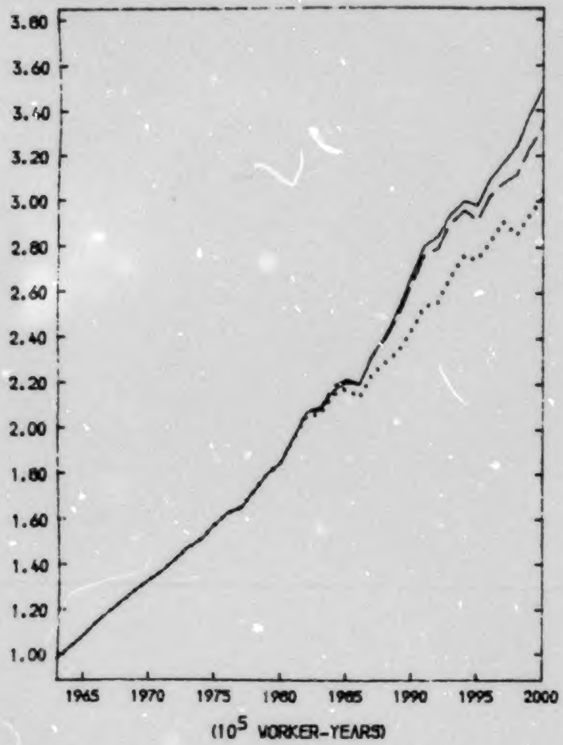
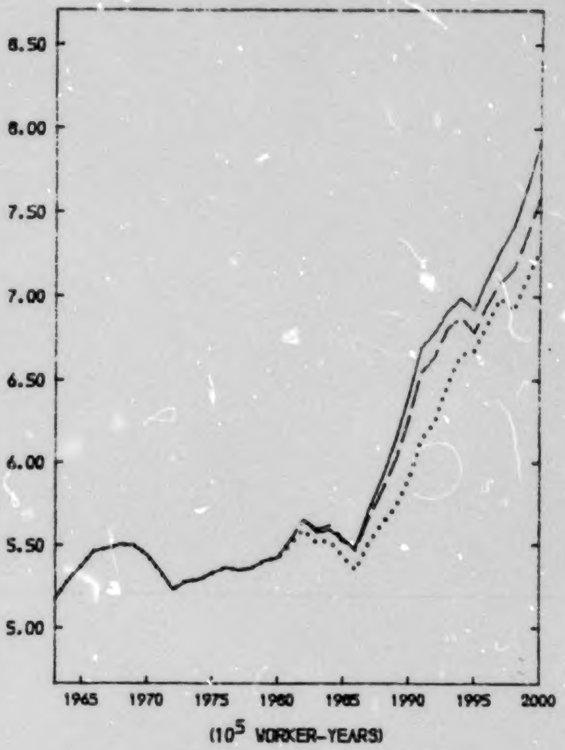
67-TRANSPORTATION AND WAREHOUSING

68-COMMUNICATIONS, EXCEPT RADIO AND TV

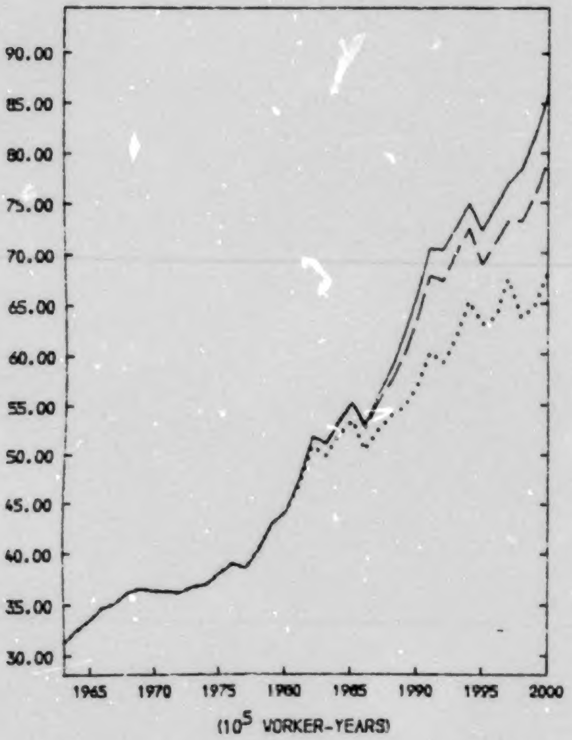
B. EMPLOYMENT BY SECTOR



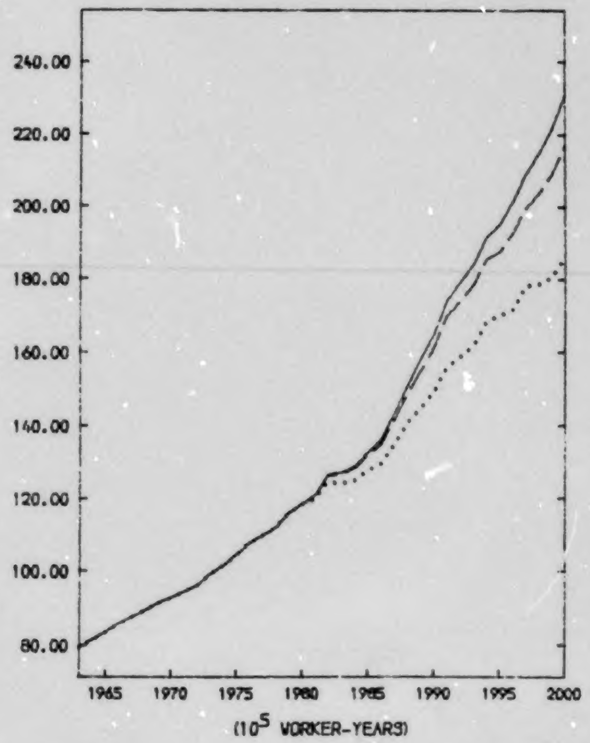
69-RADIO AND TV BROADCASTING



70-ELECTRIC, GAS AND WATER SERVICES

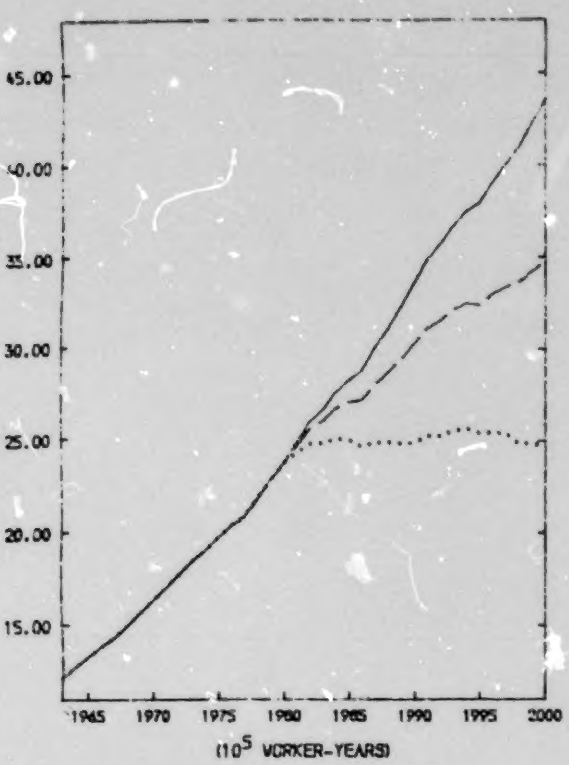


71-WHOLESALE TRADE

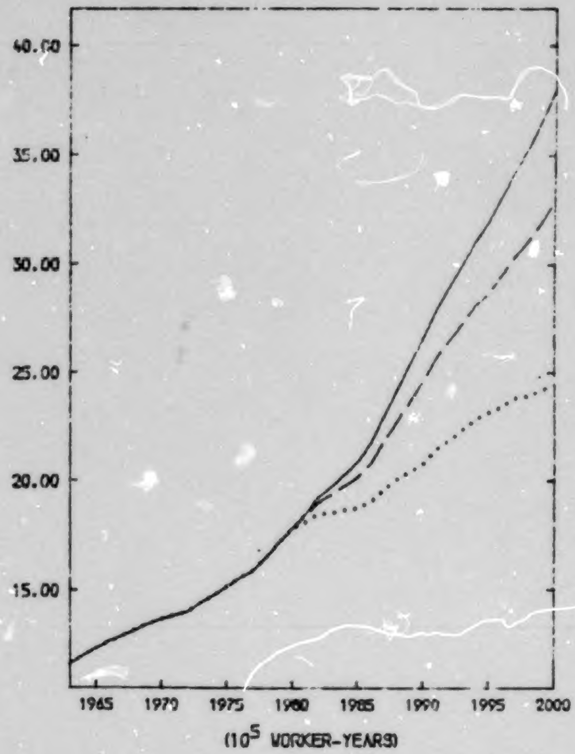


72-RETAIL TRADE

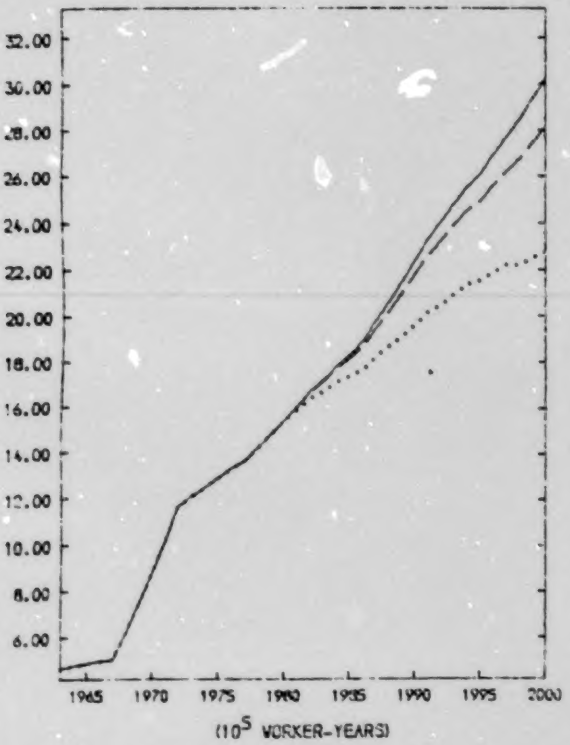
B. EMPLOYMENT BY SECTOR



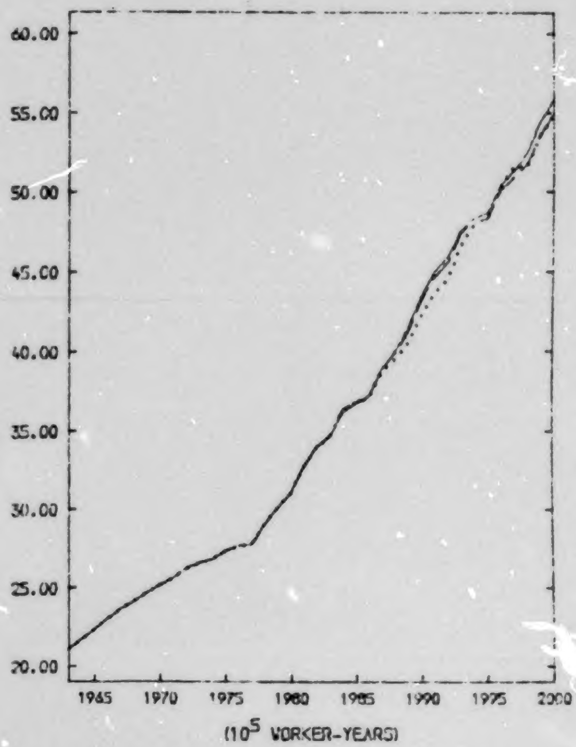
73-FINANCE



74-INSURANCE

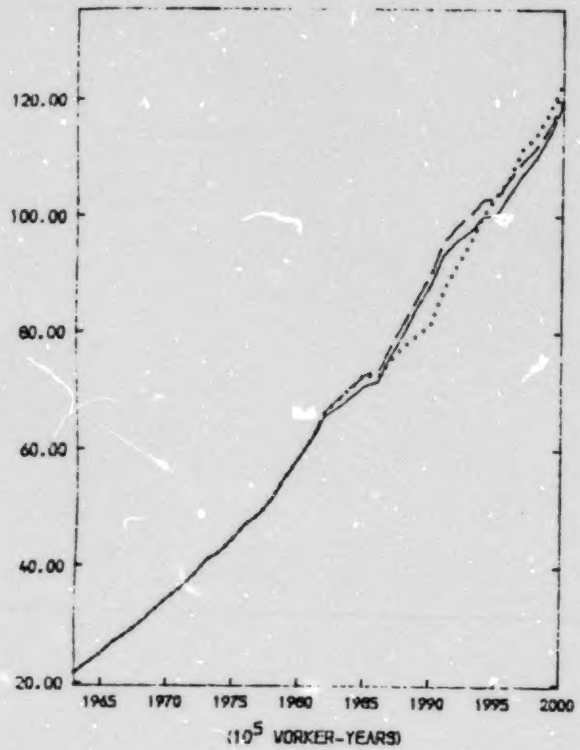


75-REAL ESTATE AND RENTAL

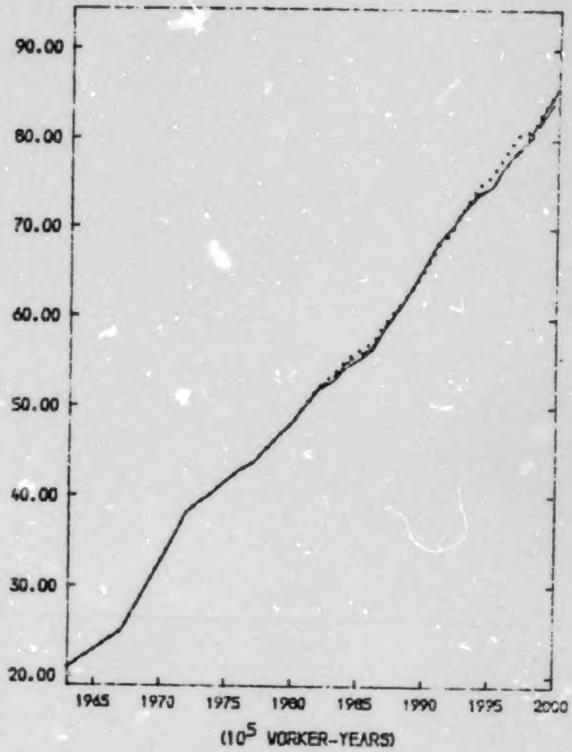


76-HOTELS, PERSONAL AND REPAIR SERVICES

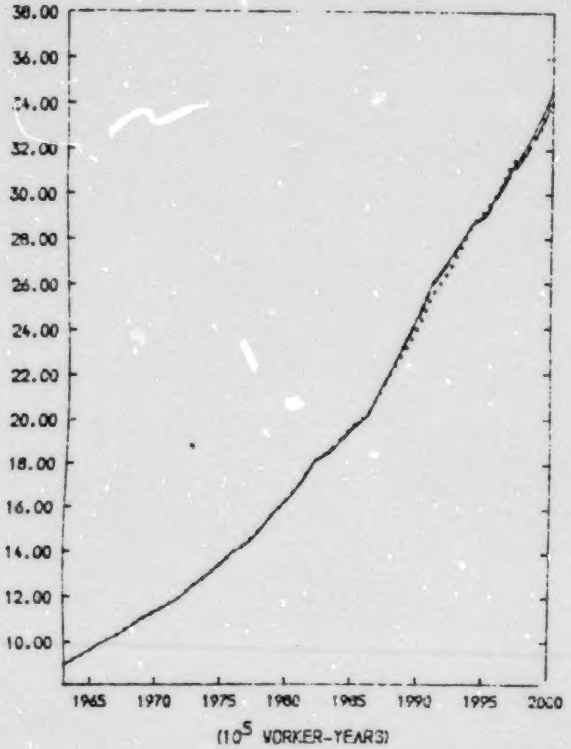
B. EMPLOYMENT BY SECTOR



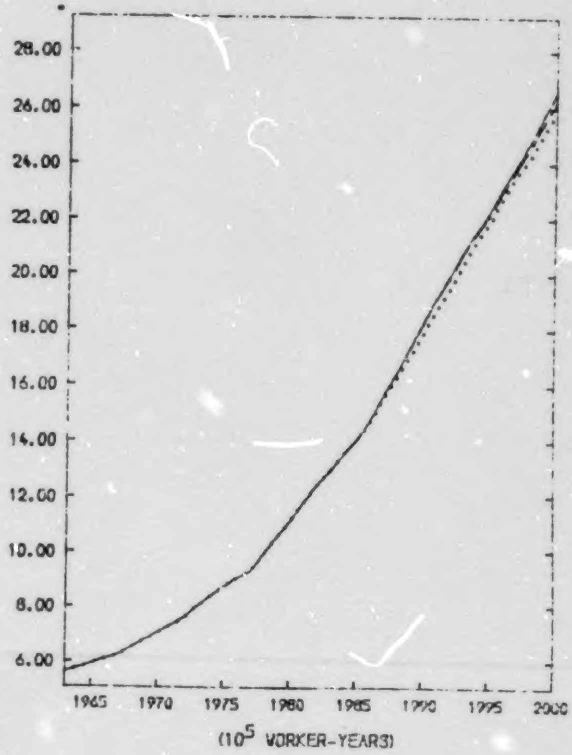
77-BUSINESS SERVICES



78-EATING AND DRINKING PLACES

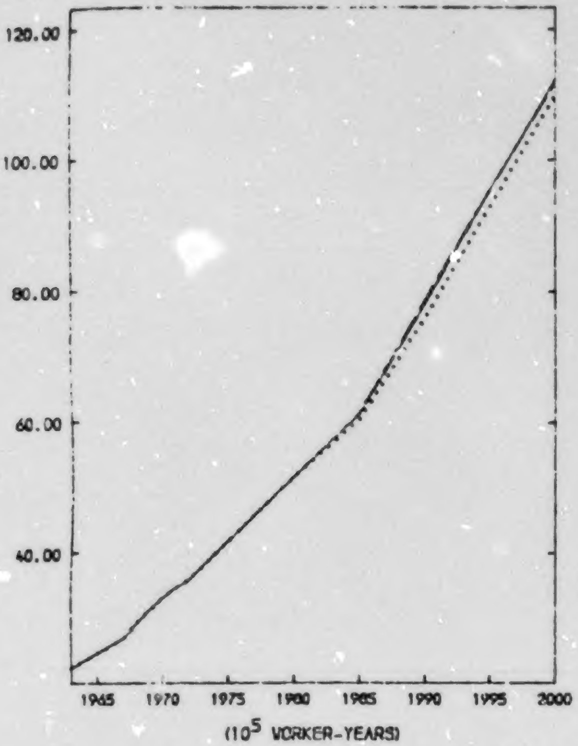


79-AUTOMOBILE REPAIR SERVICES

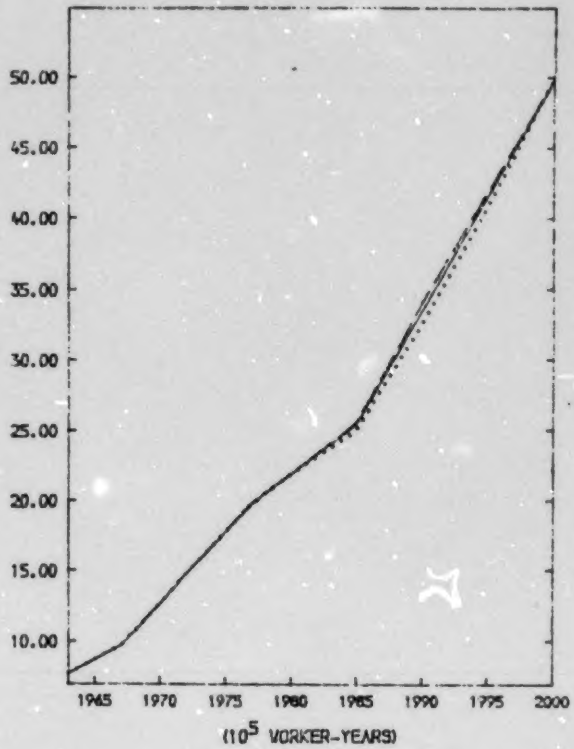


80-AMUSEMENTS

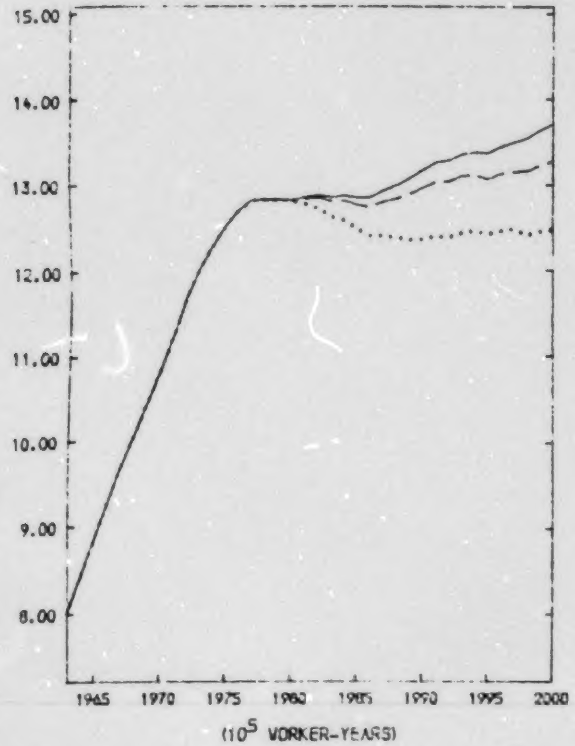
B. EMPLOYMENT BY SECTOR



81-HOSPITALS



62-HEALTH SERVICES, EXCLUDING HOSPITALS



83-EDUCATIONAL SERVICES (PRIVATE)

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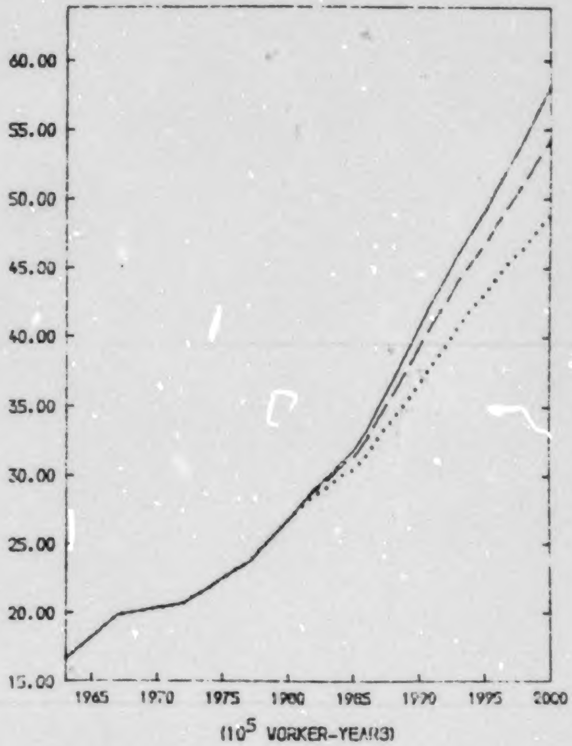
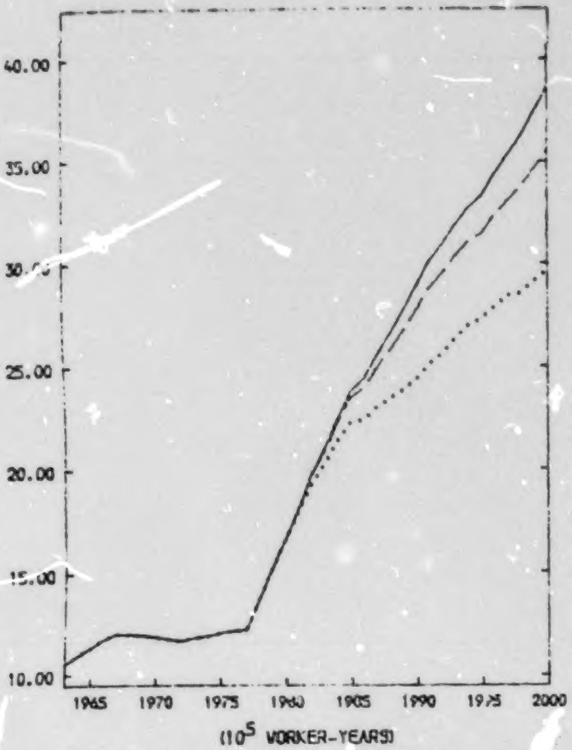
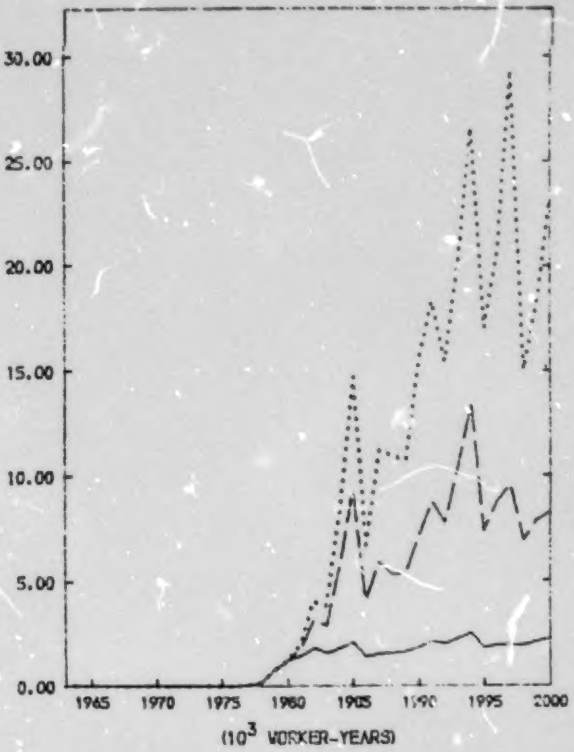


84-NONPROFIT ORGANIZATIONS

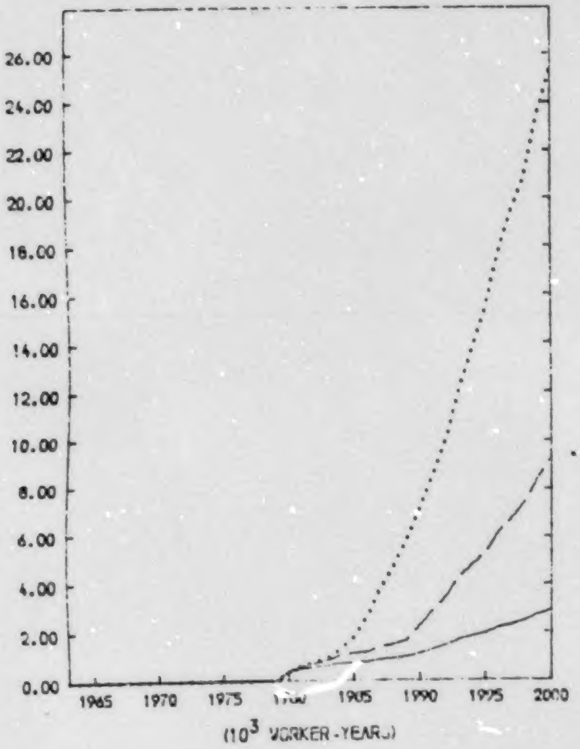
B. EMPLOYMENT BY SECTOR



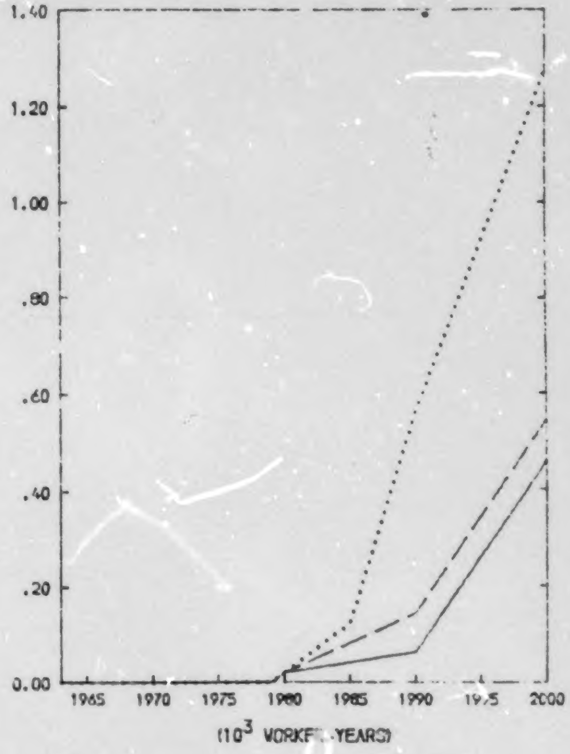
85-GOVERNMENT ENTERPRISES



86-ROBOTICS MANUFACTURING

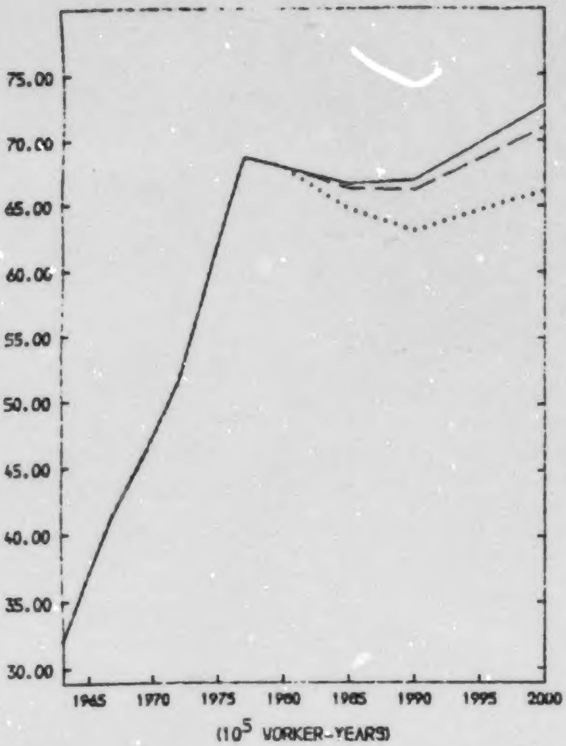


87-INSTRUCTIONAL TV

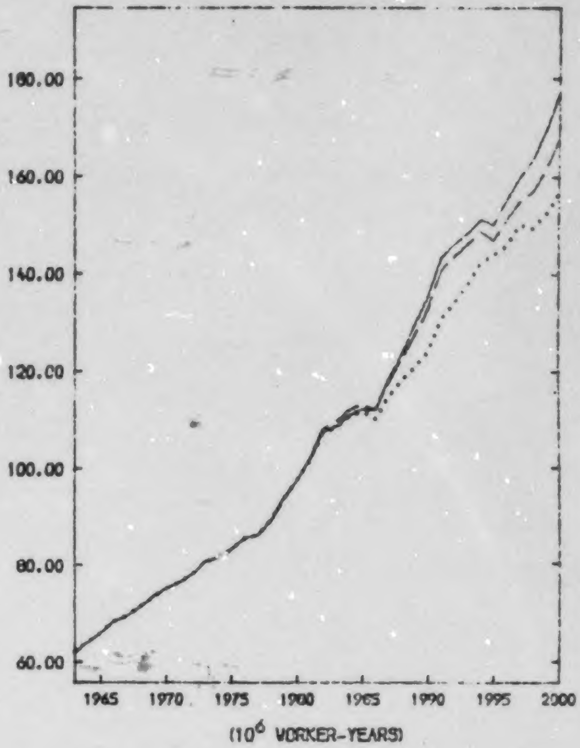


88-COMPUTER-BASED INSTRUCTION

B. EMPLOYMENT BY SECTOR

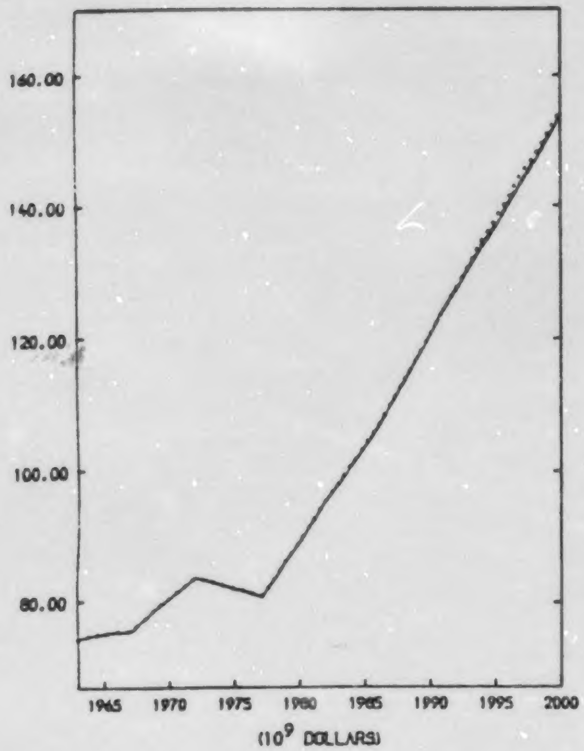


89-PUBLIC EDUCATION

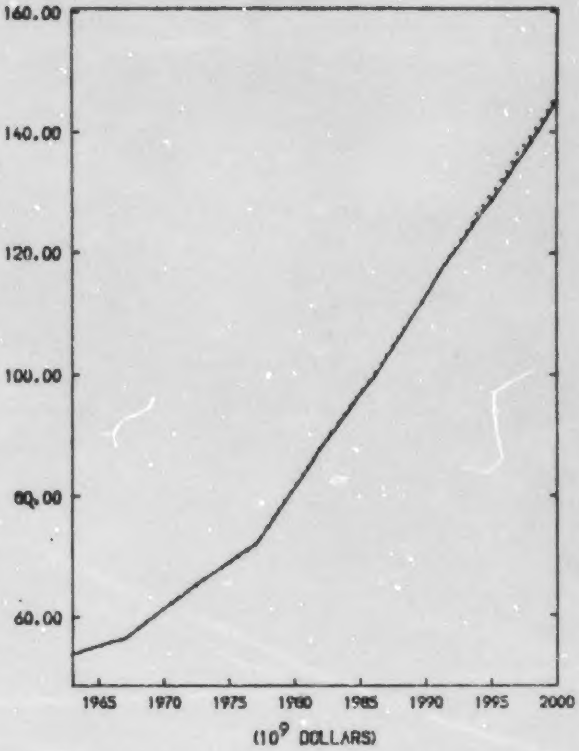


90-TOTAL

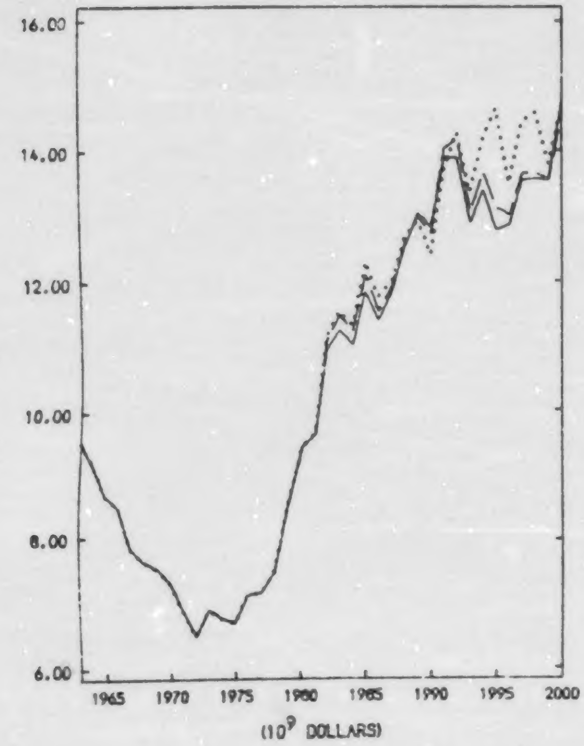
C. OUTPUT BY SECTOR



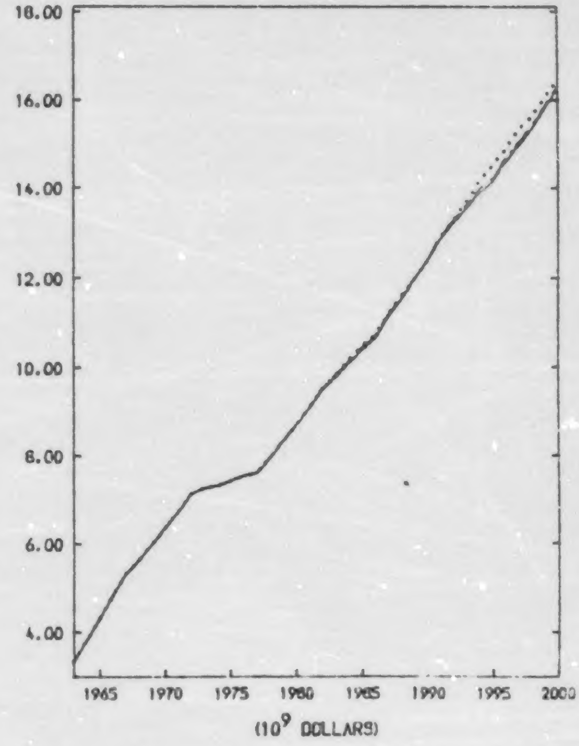
1-LIVESTOCK AND LIVESTOCK PRODUCTS



2-OTHER AGRICULTURAL PRODUCTS

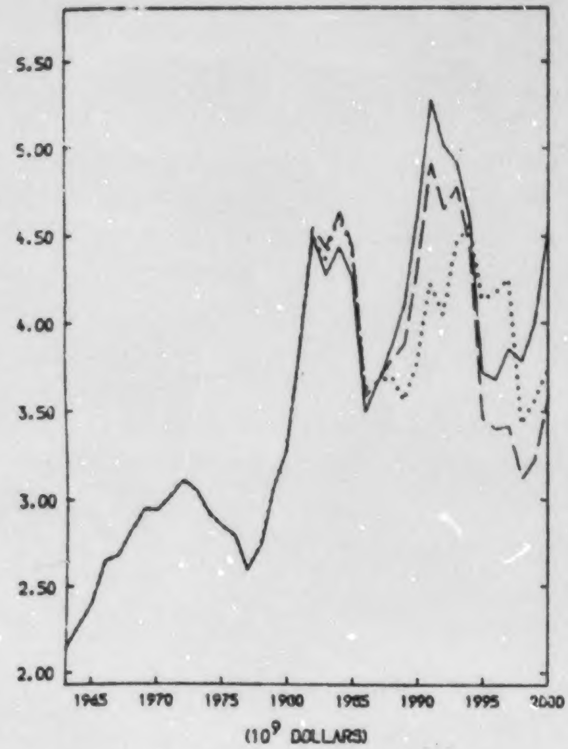


3-FORESTRY AND FISHERY PRODUCTS

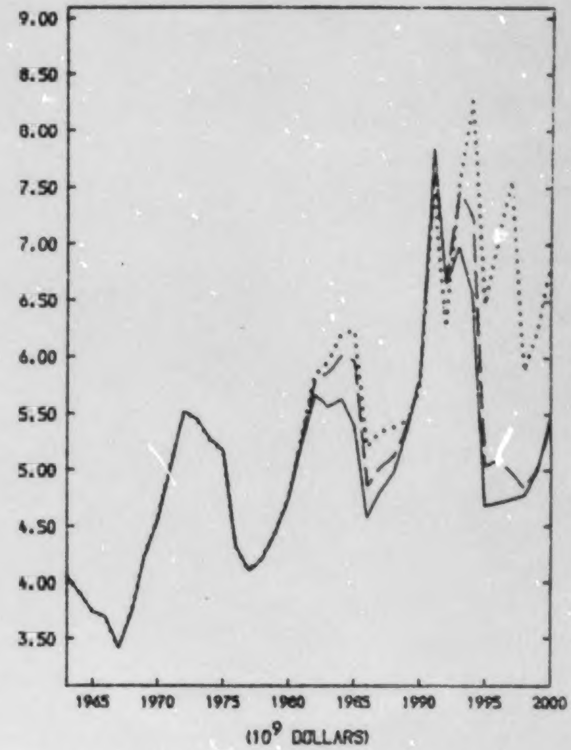


4-AGR, FORESTRY, AND FISHERY SERVICES

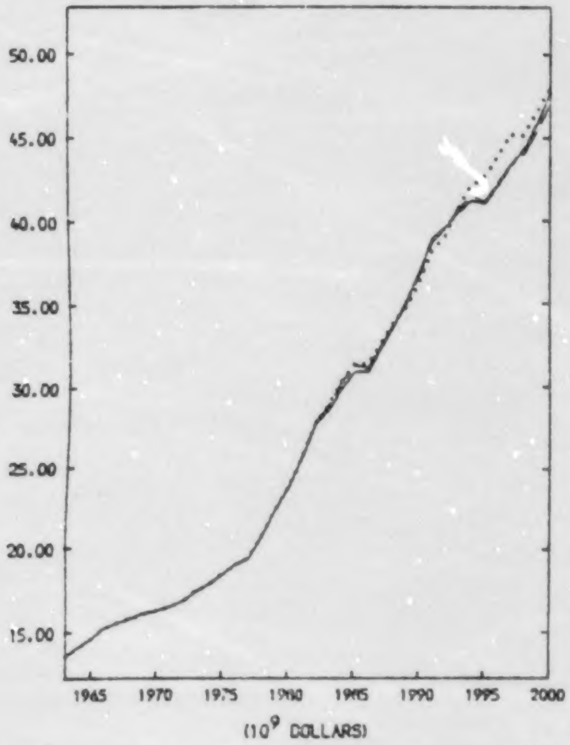
C. OUTPUT BY SECTOR

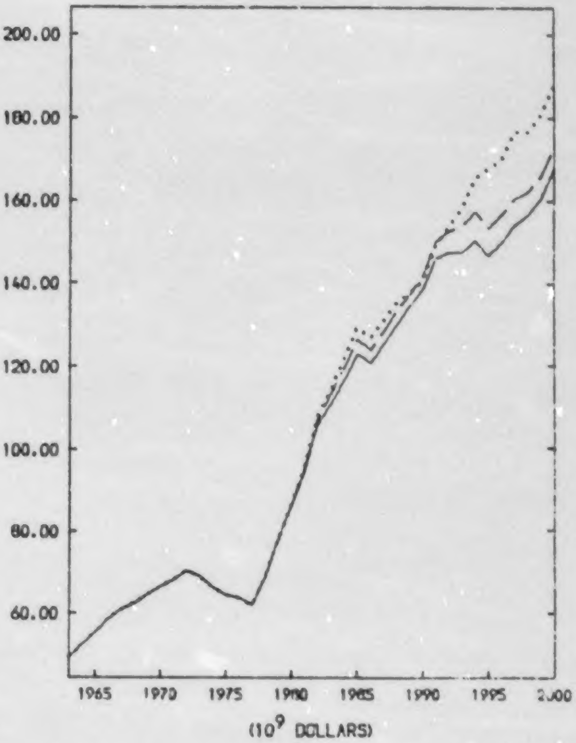


5-IRON AND FERROALLOY ORES MINING



6-NONFERROUS METAL ORES MINING





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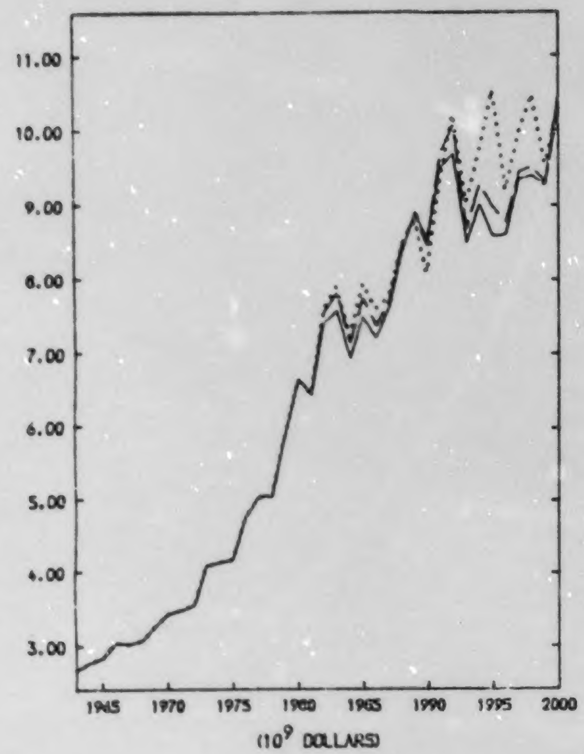
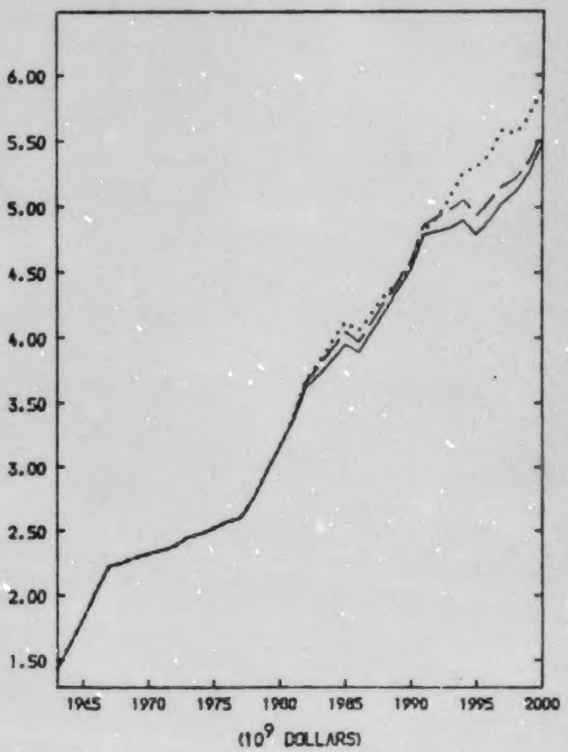
7-COAL MINING

8-CRUDE PETROLEUM AND NATURAL GAS

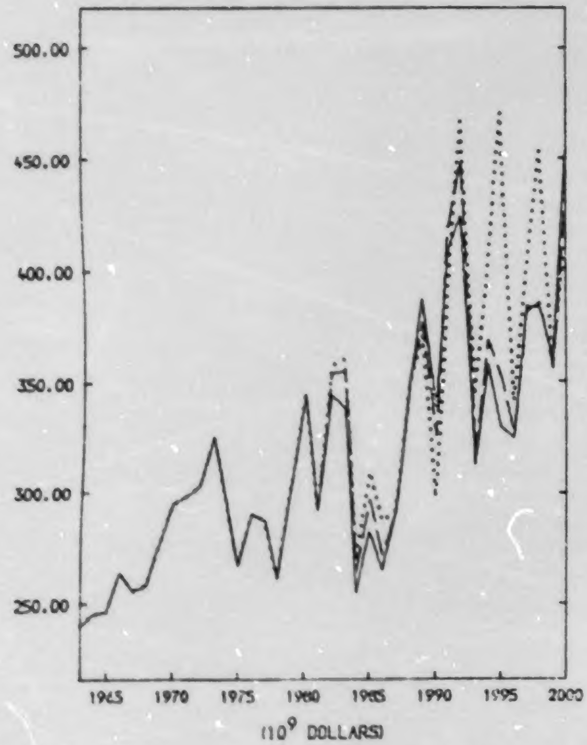
C. OUTPUT BY SECTOR



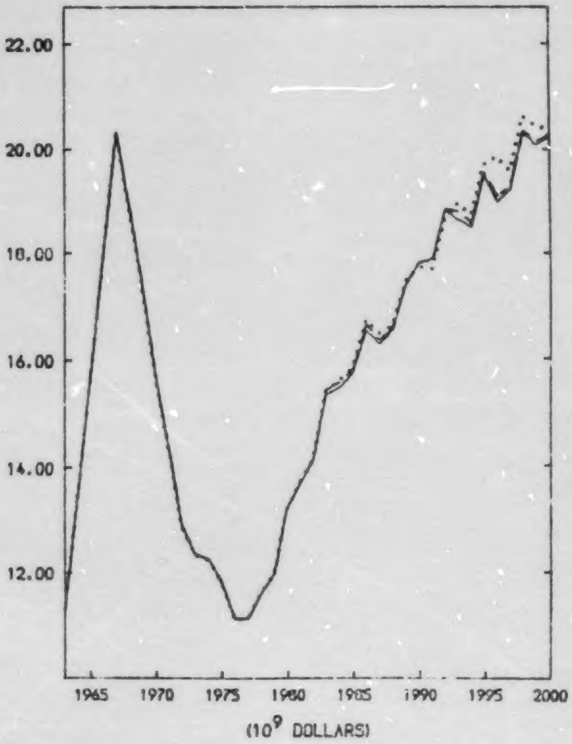
9-STONE AND CLAY MINING AND QUARRYING



10-CHEM AND FERTILIZER MINERAL MINING

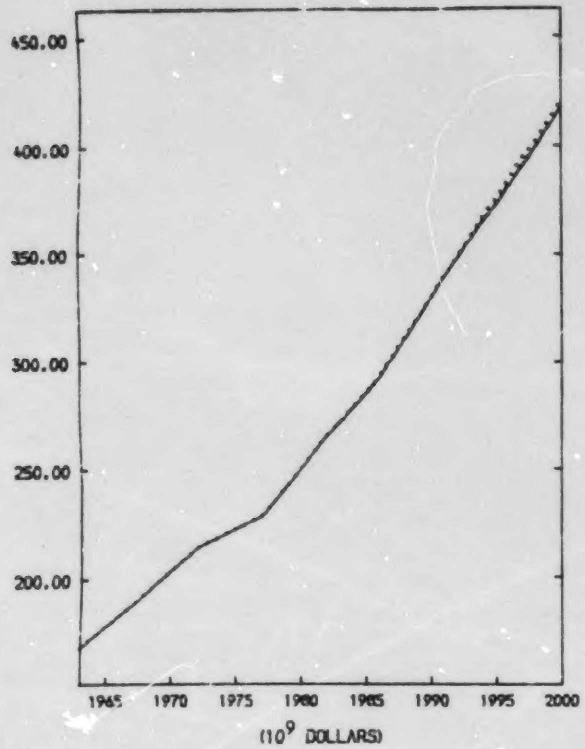


11-CONSTRUCTION

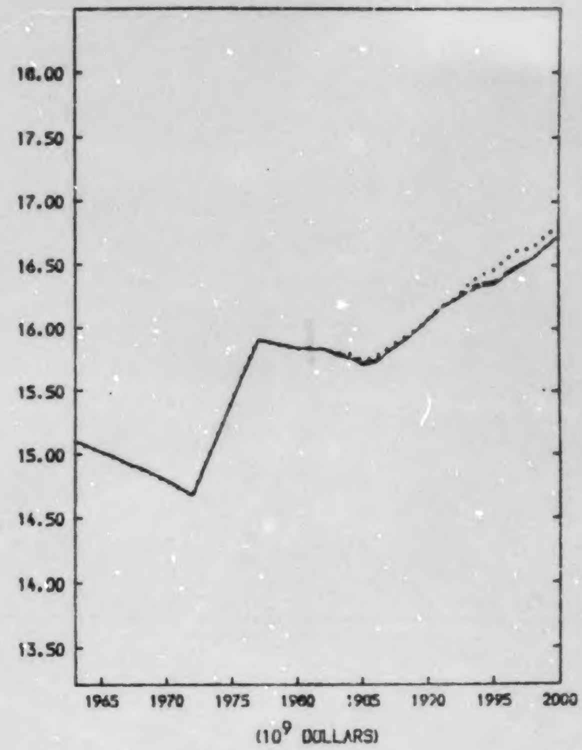


12-ORDNANCE AND ACCESSORIES

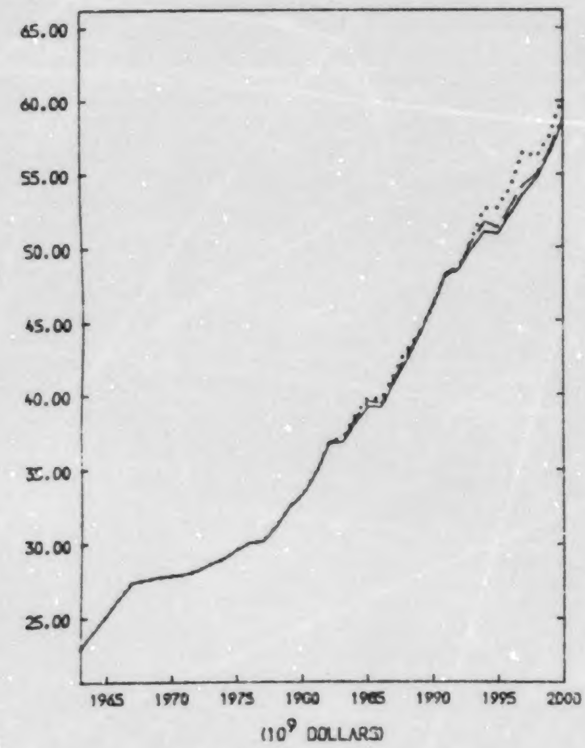
C. OUTPUT BY SECTOR



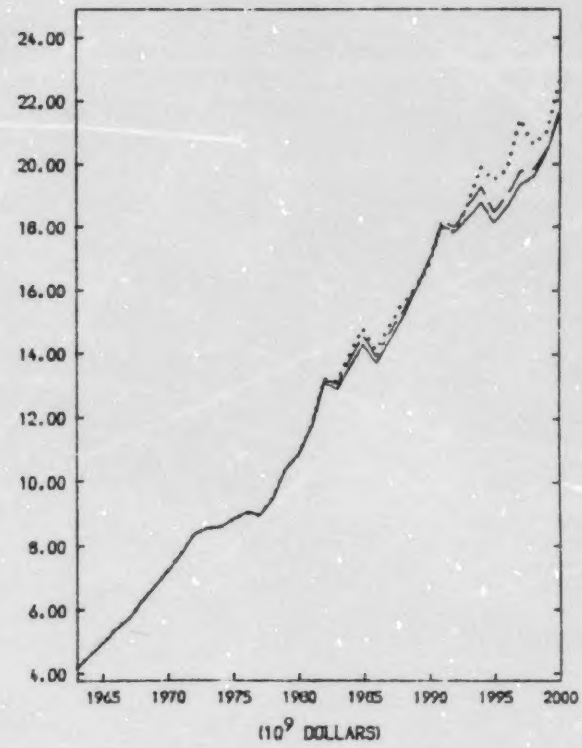
13-FOOD AND KINDRED PRODUCTS



14-TOBACCO

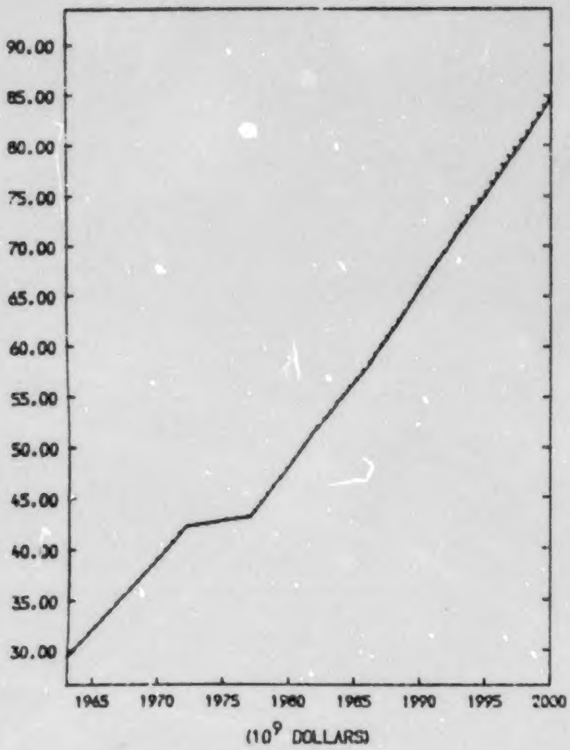


15-FABRICS, YARN AND THREAD MILLS

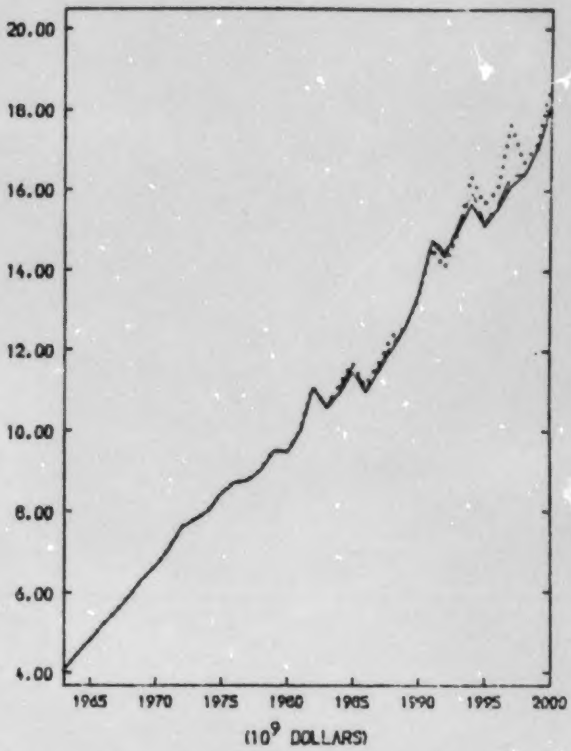


16-MISC TEXTILE GOODS AND FLOOR COVERING

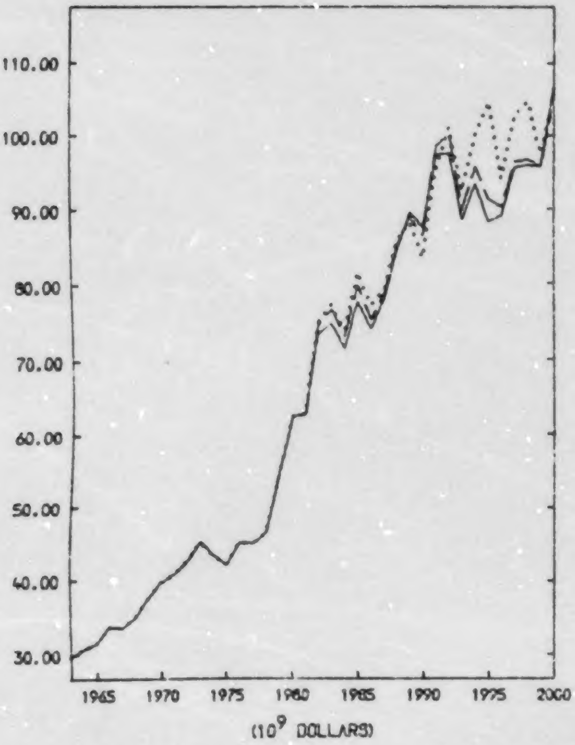
C. OUTPUT BY SECTOR



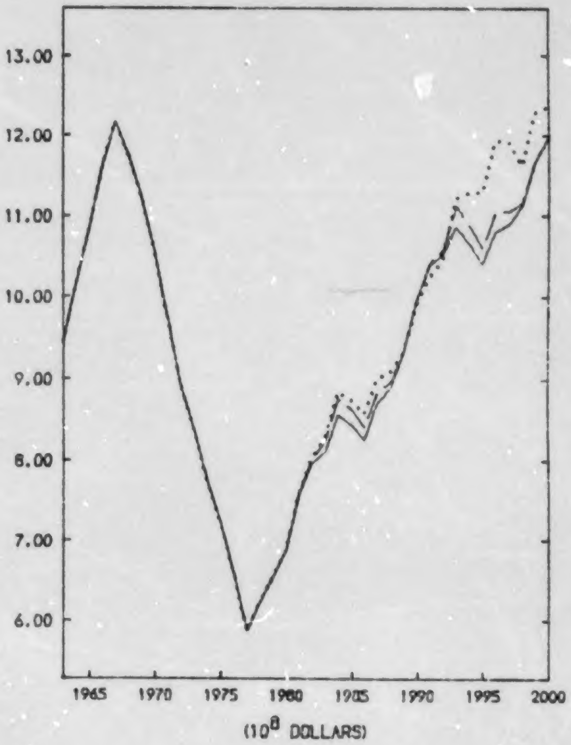
17-APPAREL



18-MISC FABRICATED TEXTILE PRODUCTS

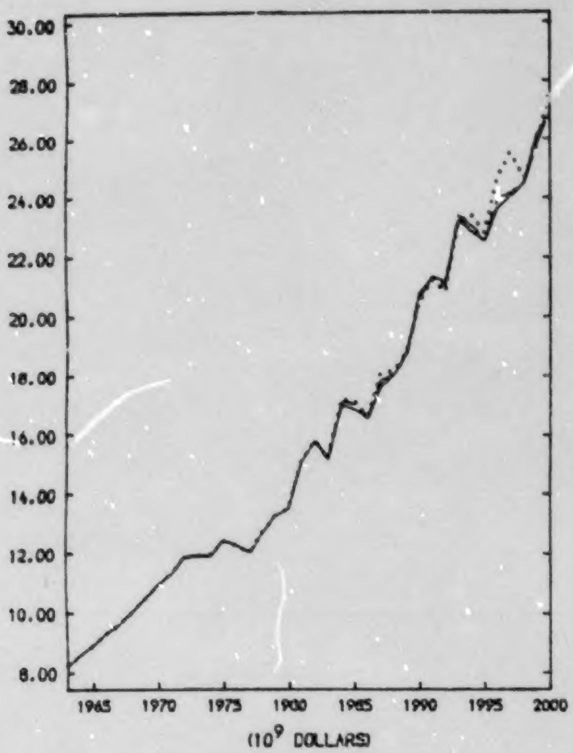


19-LUMBER AND WOOD PROD, EXC CONTAINERS

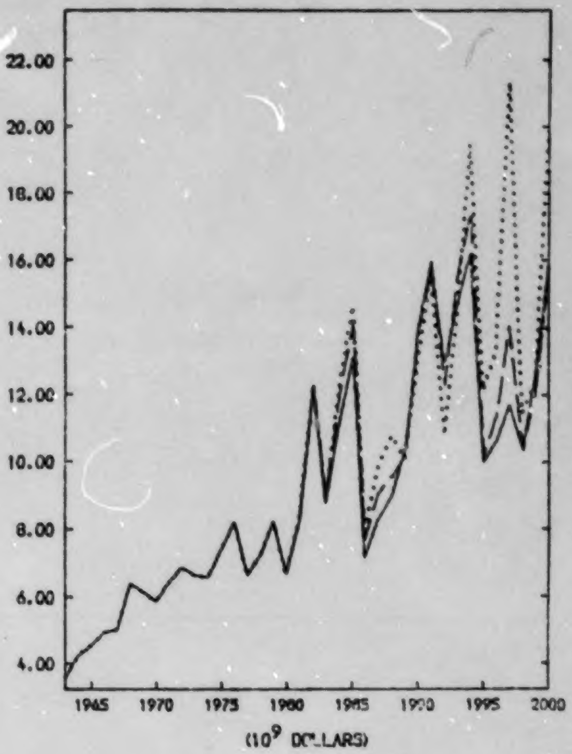


20-WOOD CONTAINERS

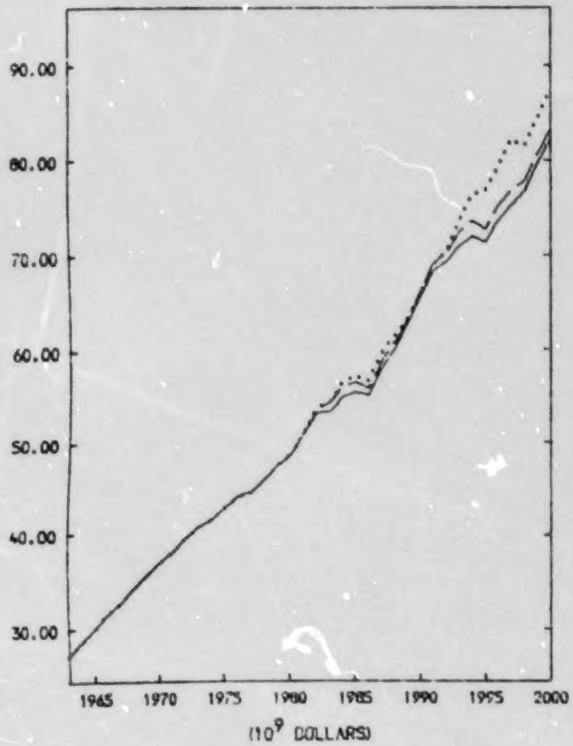
C. OUTPUT BY SECTOR



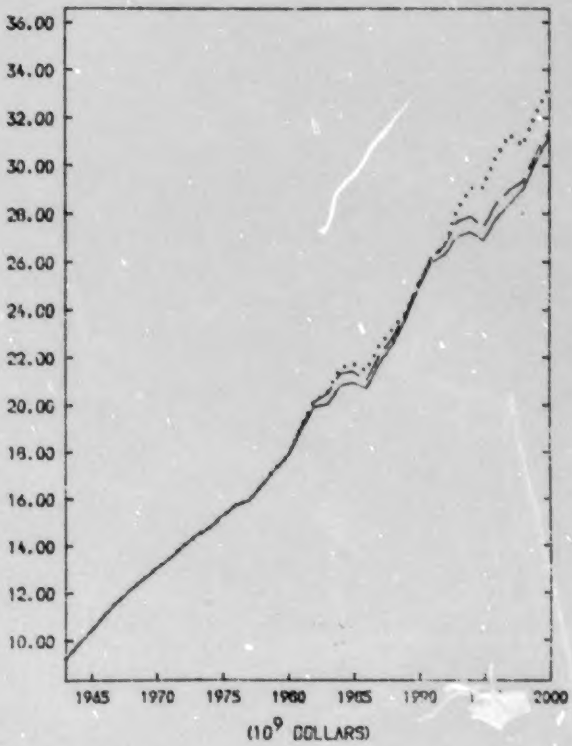
21-HOUSEHOLD FURNITURE



22-OTHER FURNITURE AND FIXTURES

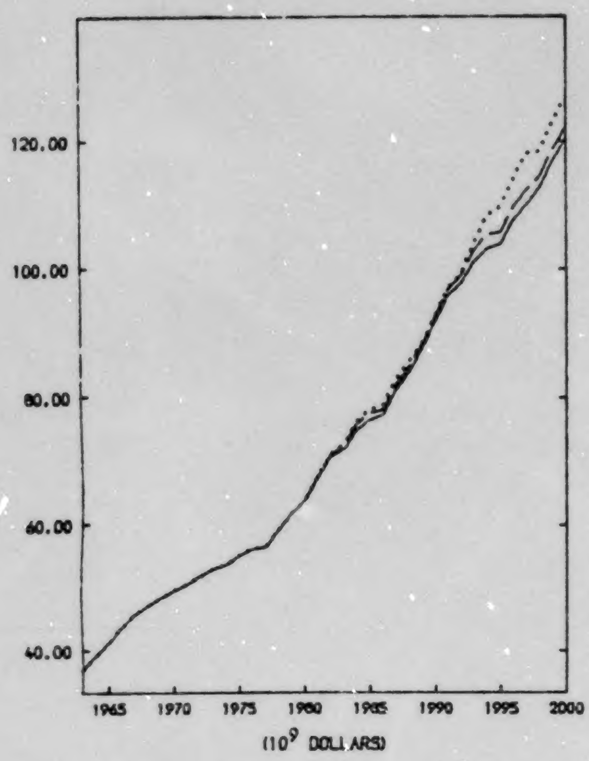


23-PAPER AND ALLIED PROD, EXC CONTAINERS

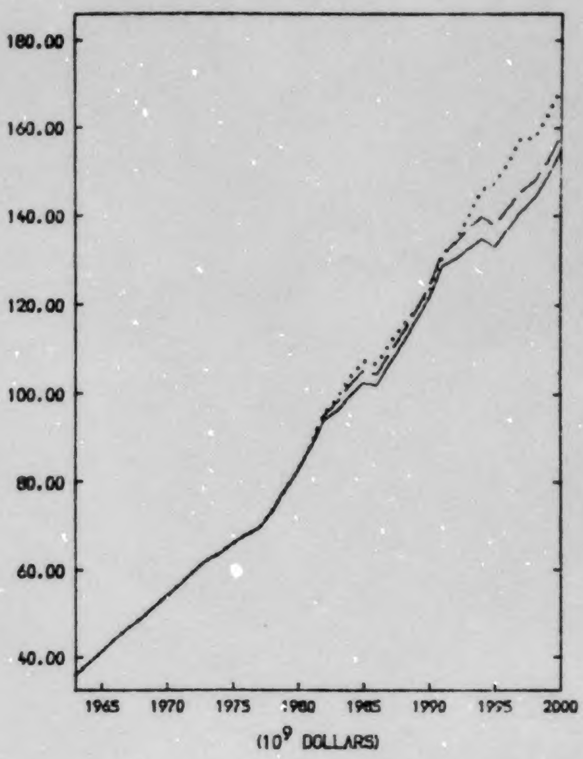


24-PAPERBOARD CONTAINERS AND BOXES

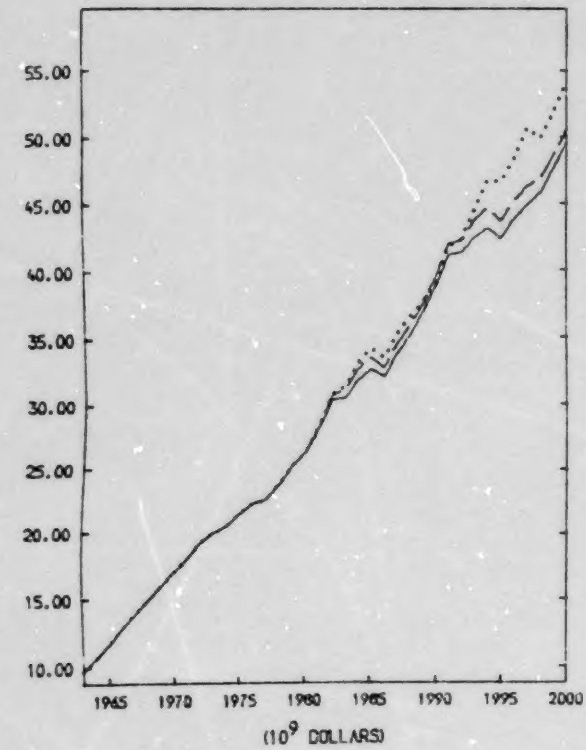
C. OUTPUT BY SECTOR



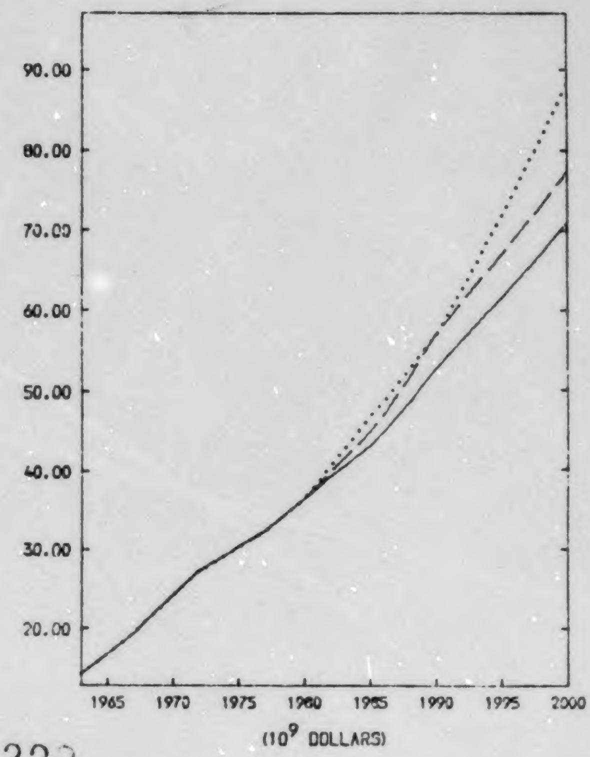
25-PRINTING AND PUBLISHING



26-CHEMICALS AND SELECTED CHEM PRODUCTS



27-PLASTICS AND SYNTHETIC MATERIALS



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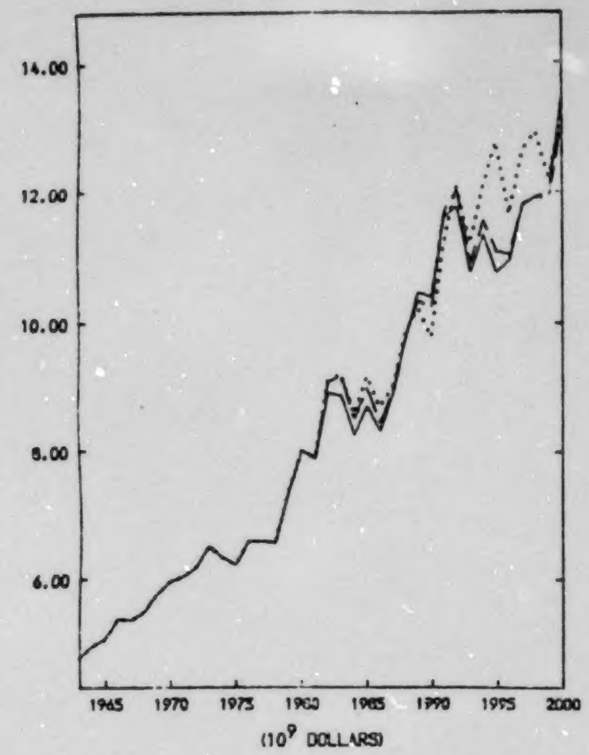
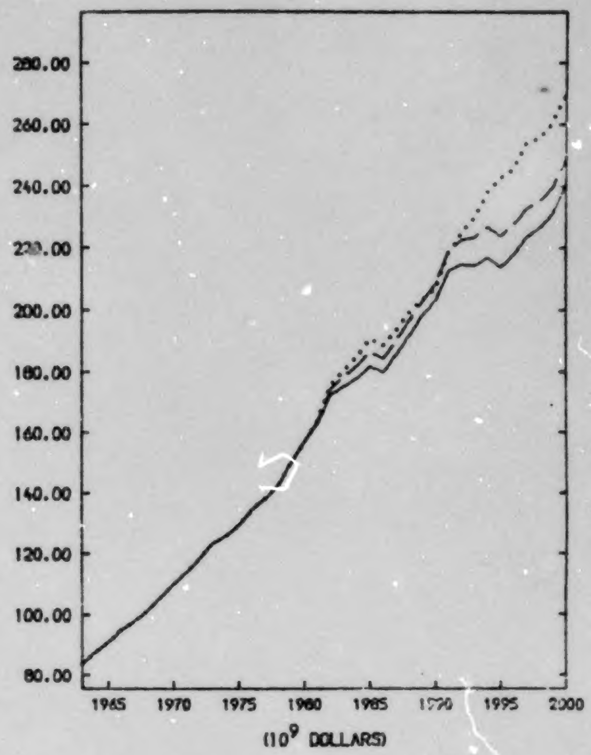
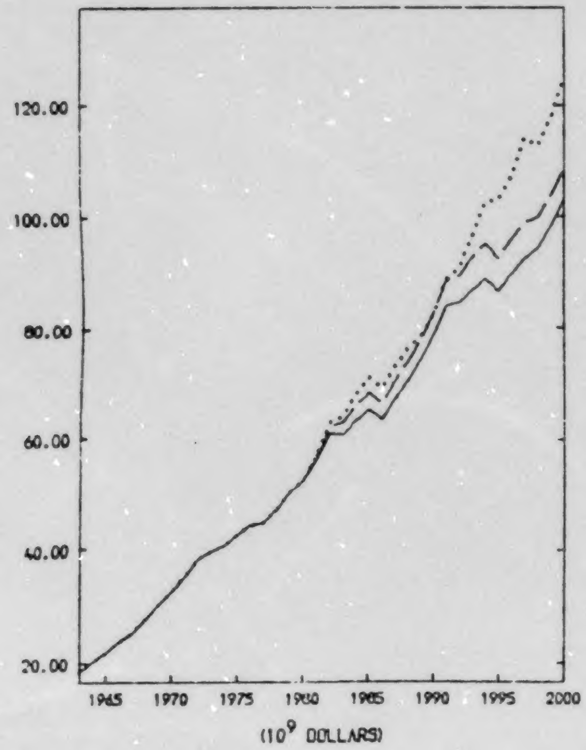
28-DRUGS,CLEANING AND TOILET PREPARATION



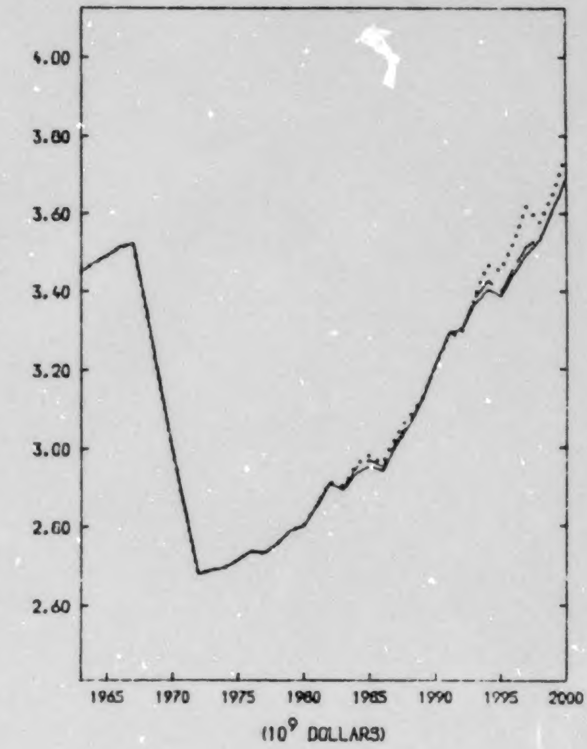
29-PAINTS AND ALLIED PRODUCTS



30-PETROLEUM REFINING AND ALLIED IND.

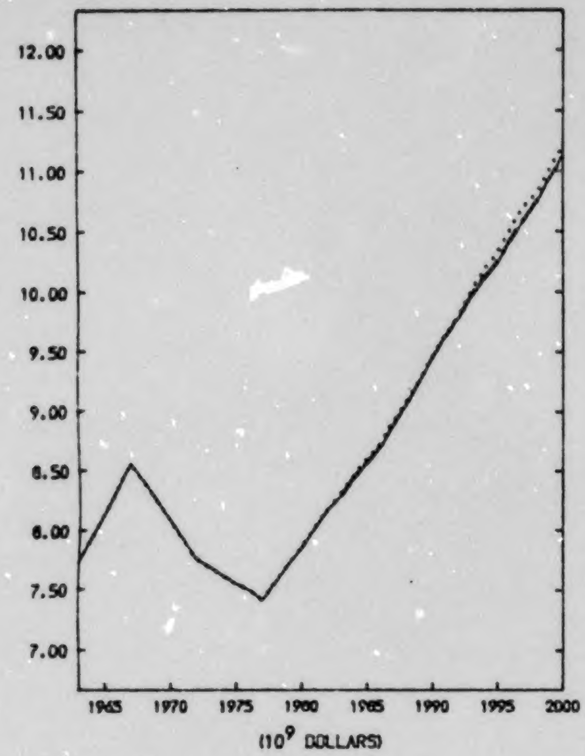


31-RUBBER AND MISC PLASTIC PRODUCTS

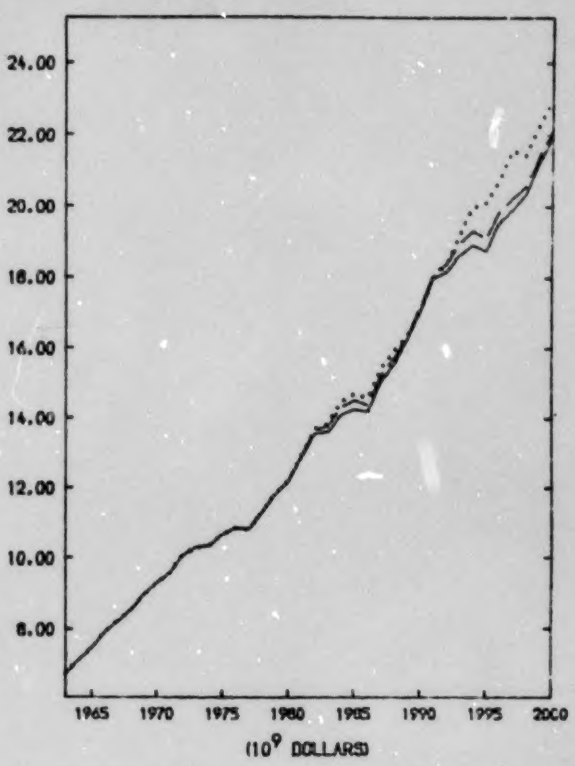


32-LEATHER TANNING AND FINISHING

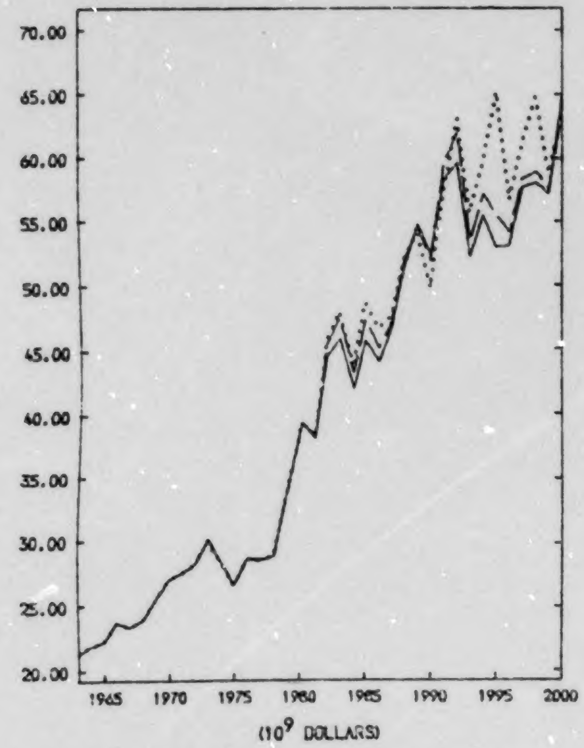
C. OUTPUT BY SECTOR



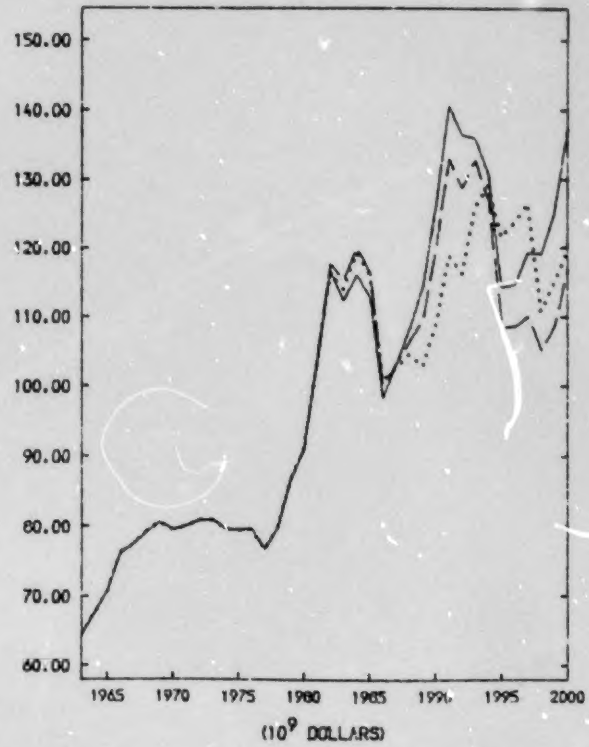
33-FOOTWEAR AND OTHER LEATHER PRODUCTS



34-GLASS AND GLASS PRODUCTS

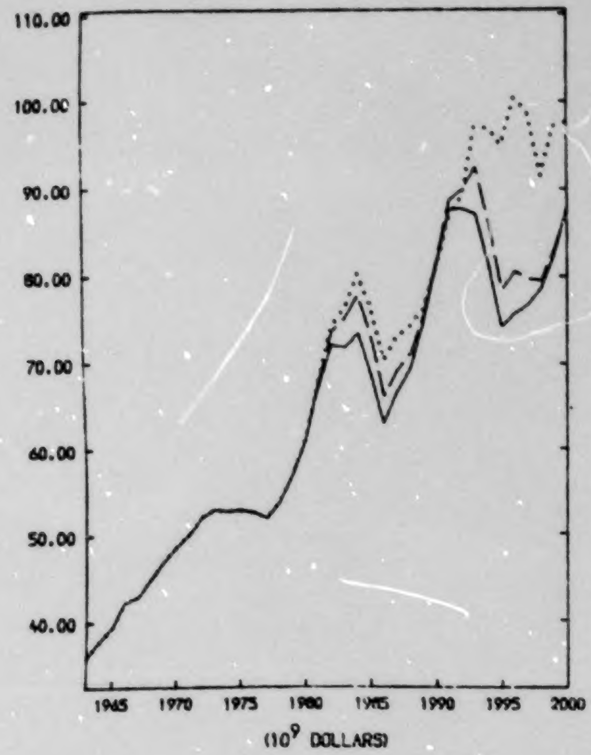


35-STONE AND CLAY PRODUCTS

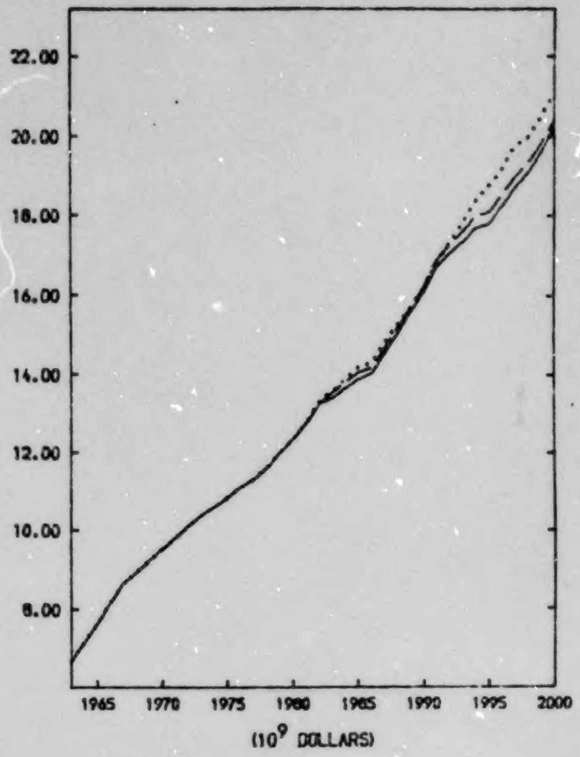


36-PRIMARY IRON AND STEEL MANUFACTURING

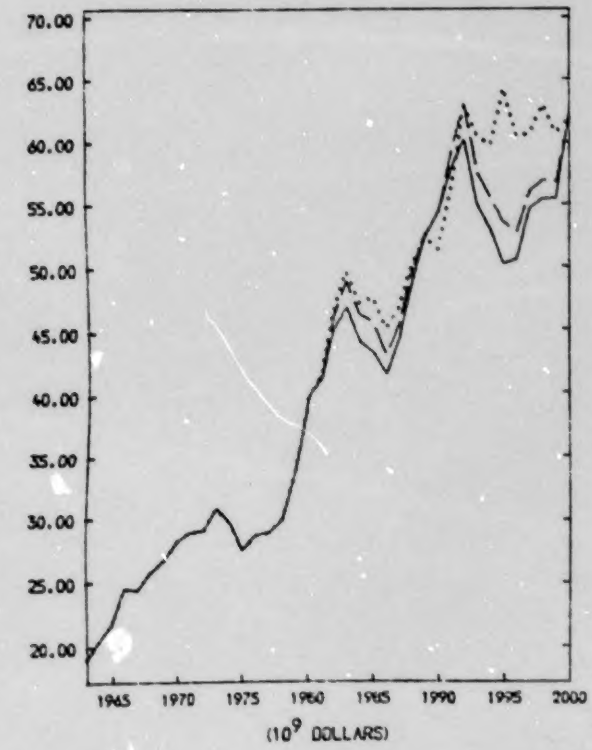
C. OUTPUT BY SECTOR



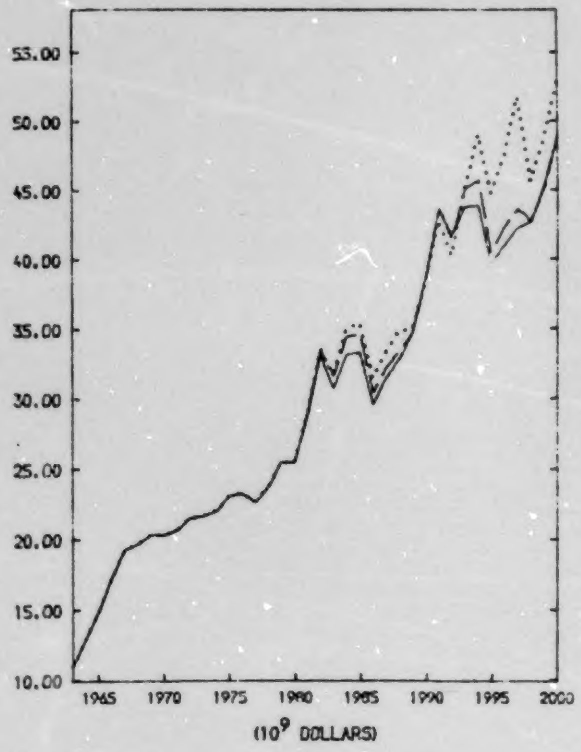
37-PRIMARY NONFERROUS METALS MANUFACTURE



38-METAL CONTAINERS

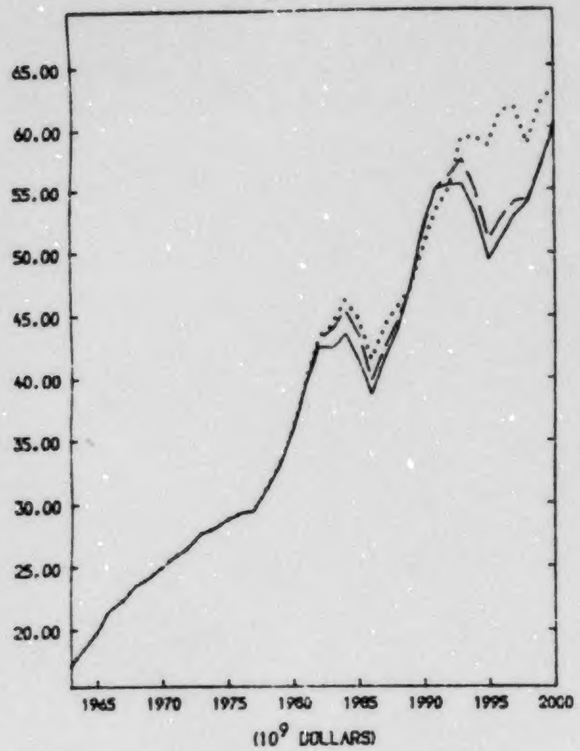


39-HEATING, PLUMBING, OTHER METAL PRODUCTS

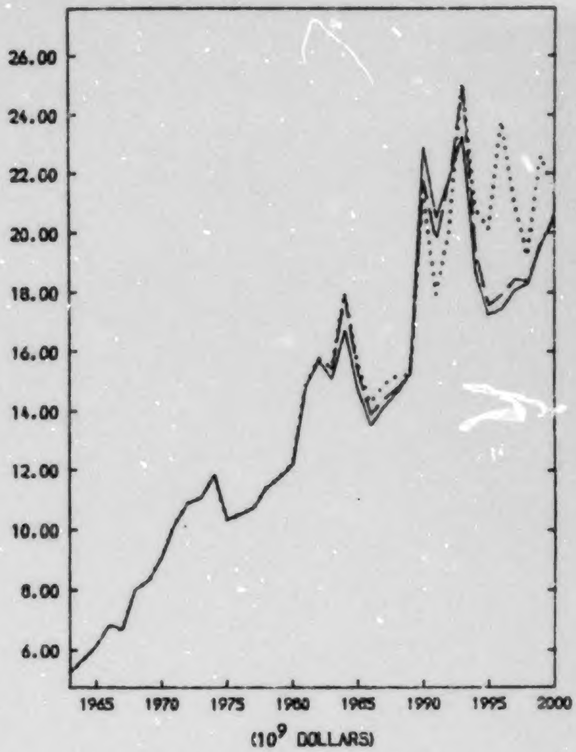


40-SCREW MACHINE PRODUCTS AND STAMPINGS

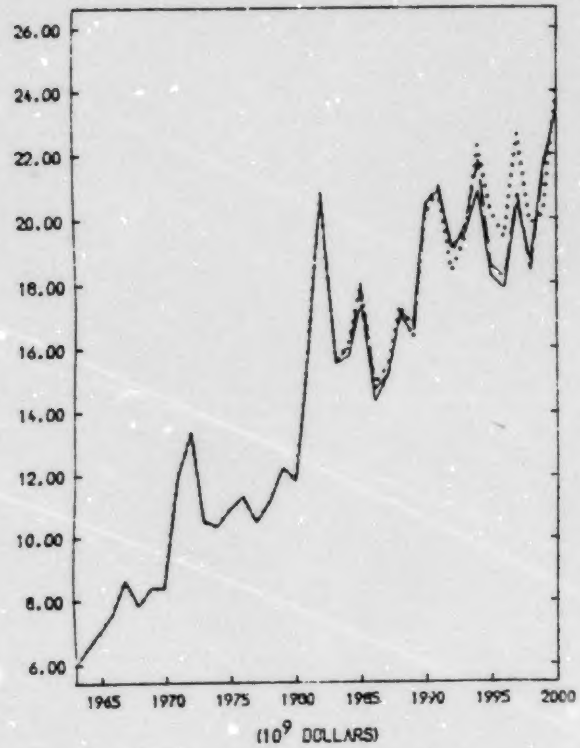
C. OUTPUT BY SECTOR



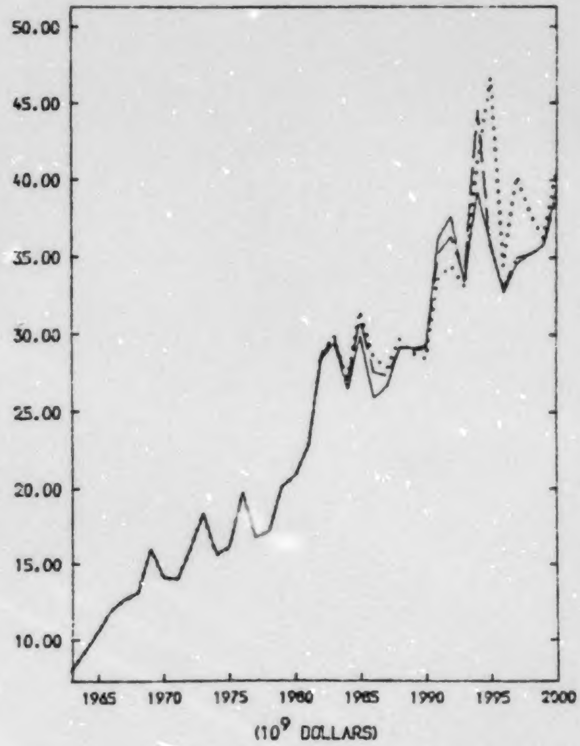
41-OTHER FABRICATED METAL PRODUCTS



42-ENGINES AND TURBINES

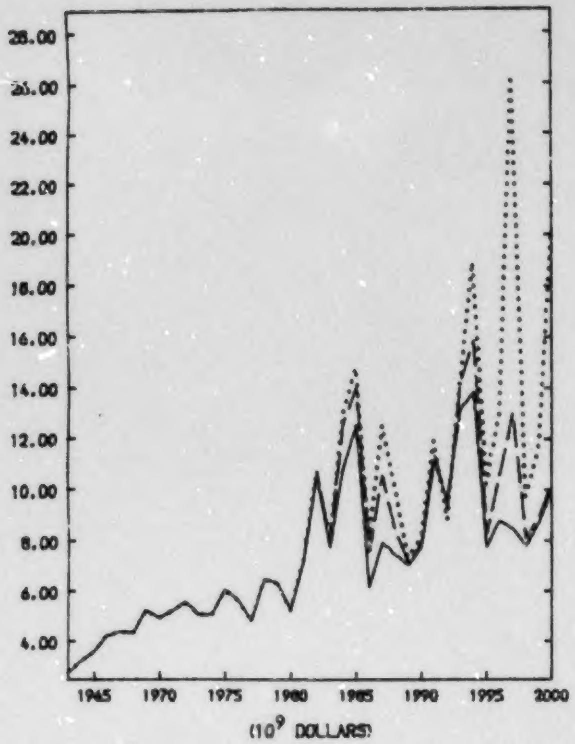


43-FARM AND GARDEN MACHINERY

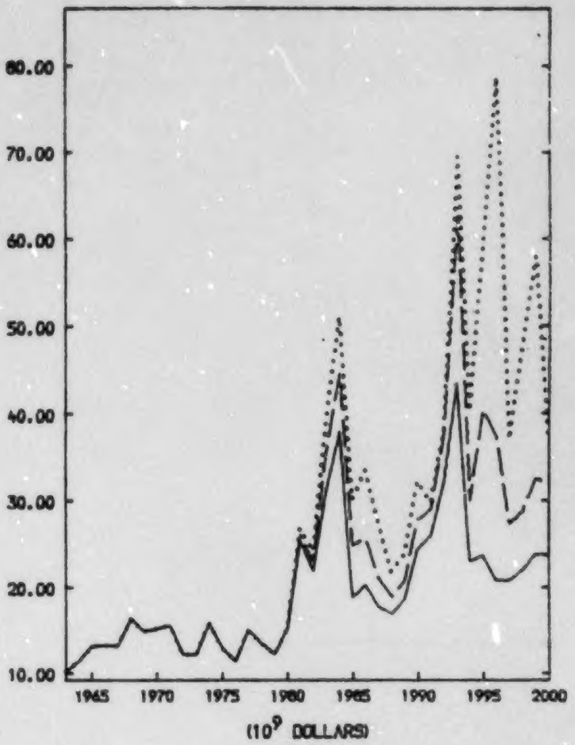


44-CONSTRUCTION AND MINING MACHINERY

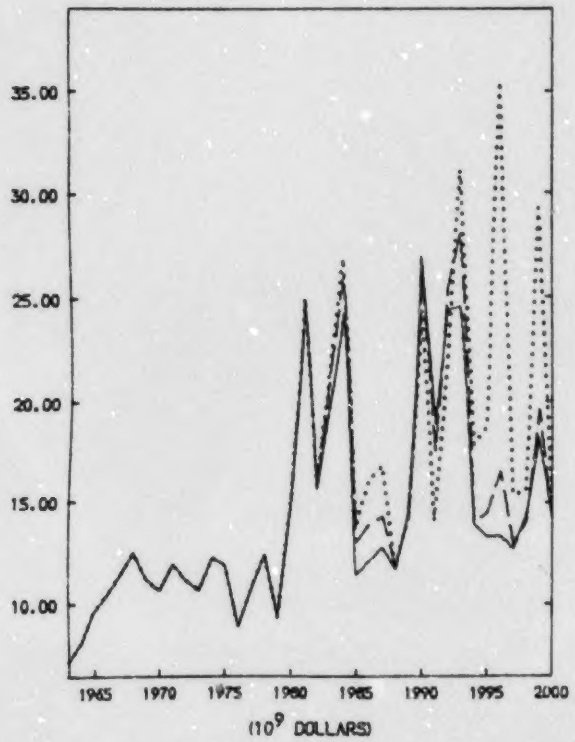
C. OUTPUT BY SECTOR



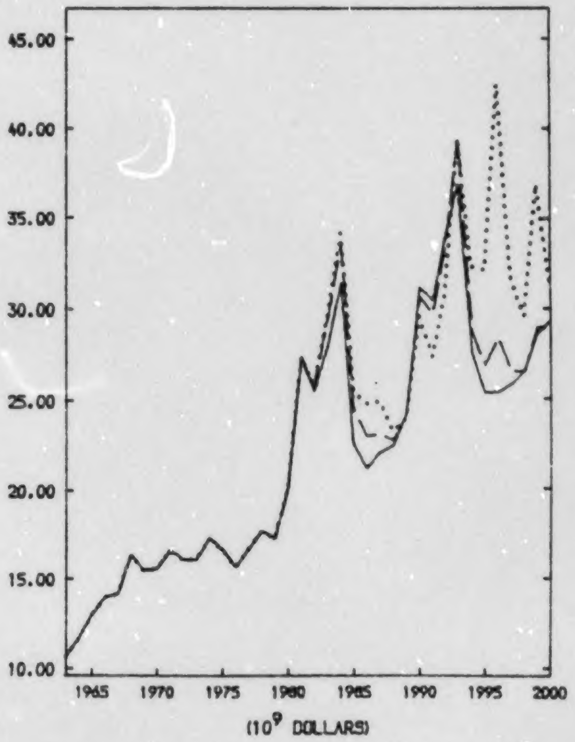
45-MATERIALS HANDLING EQUIPMENT



46-METALVOPKING MACHINERY AND EQUIPMENT

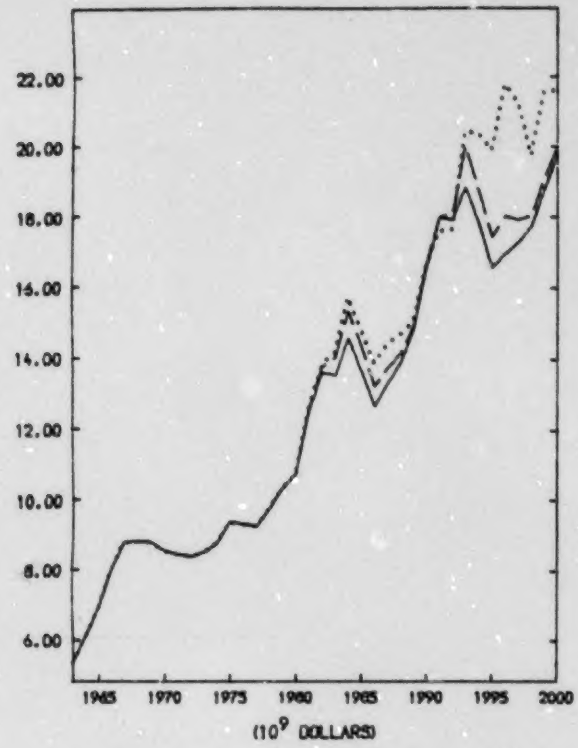


47-SPECIAL INDUSTRY EQUIPMENT

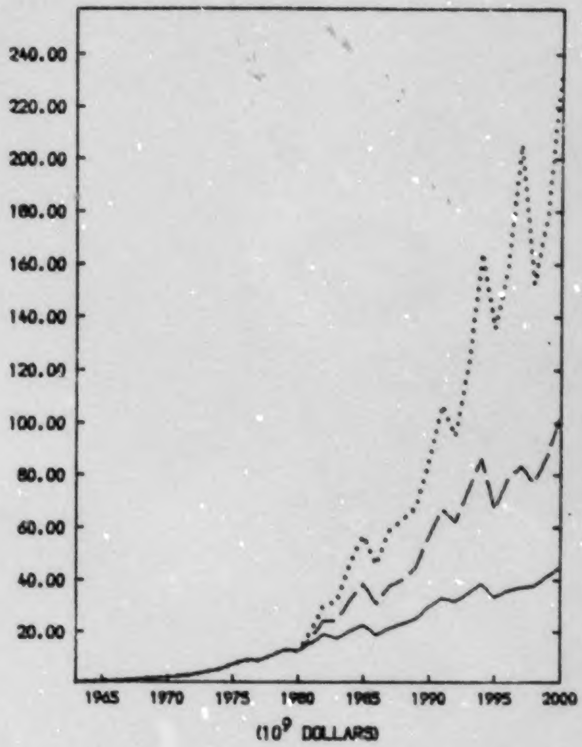


48-GENERAL INDUSTRIAL EQUIPMENT

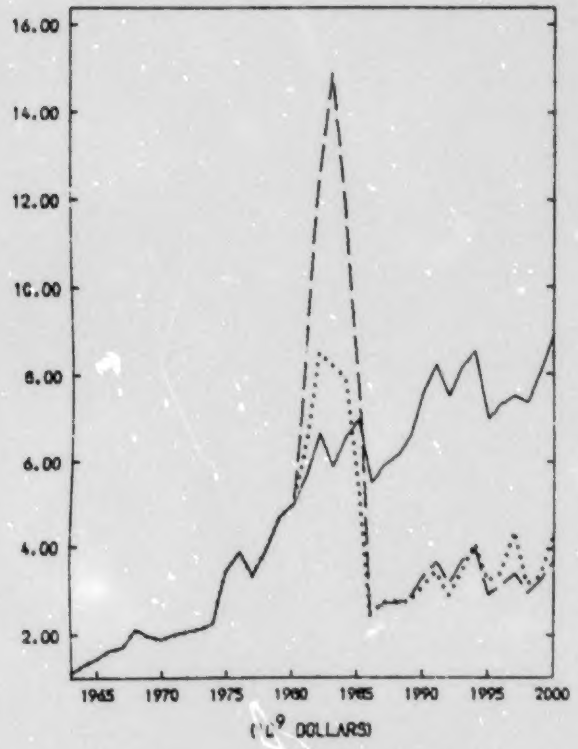
C. OUTPUT BY SECTOR



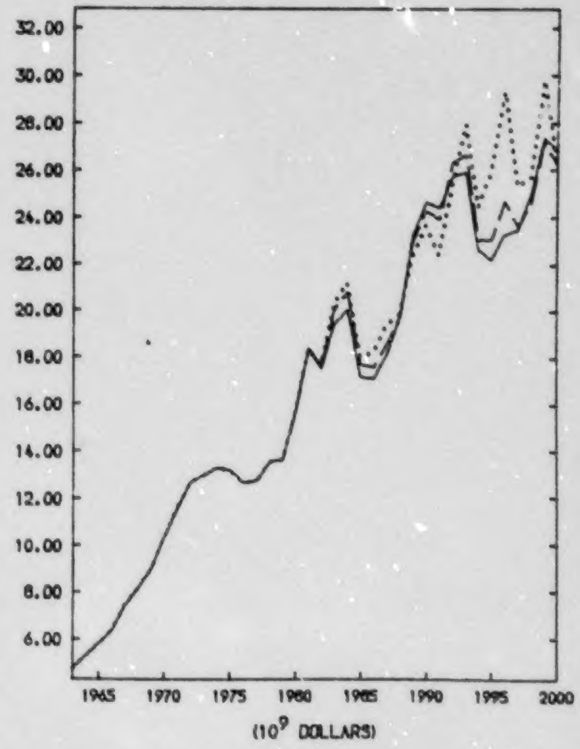
49-MISC MACHINERY, EXCEPT ELECTRICAL



50-ELECTRONIC COMPUTING EQUIPMENT

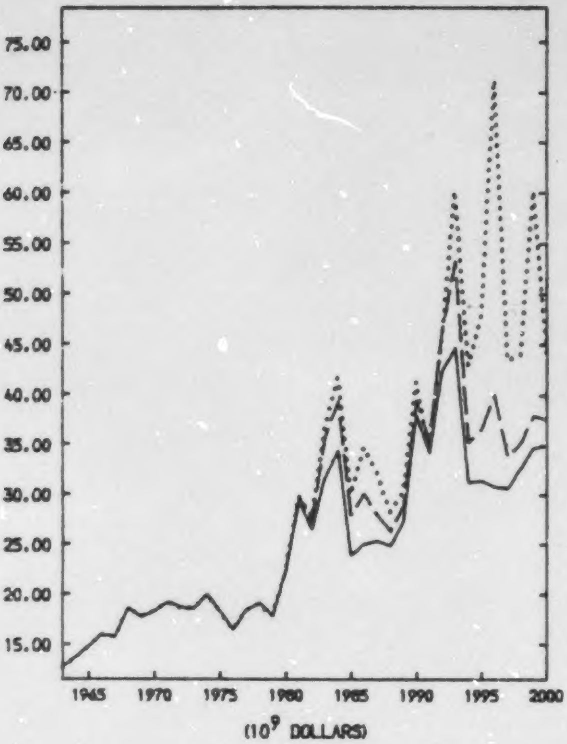


51-OFFICE MACHINES, EXCEPT COMPUTERS

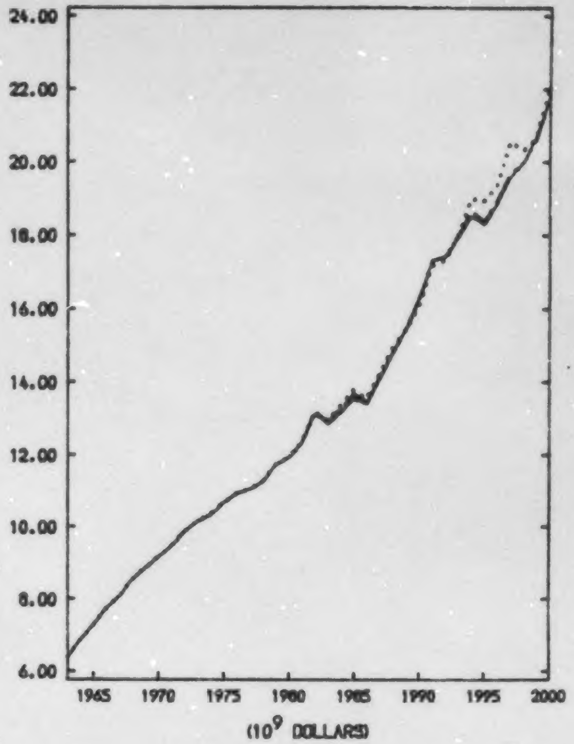


52-SERVICE INDUSTRY MACHINES

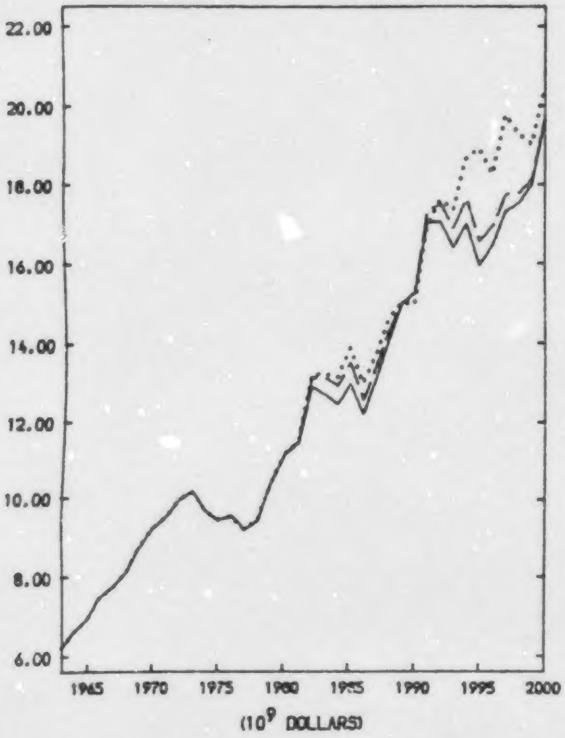
C. OUTPUT BY SECTOR



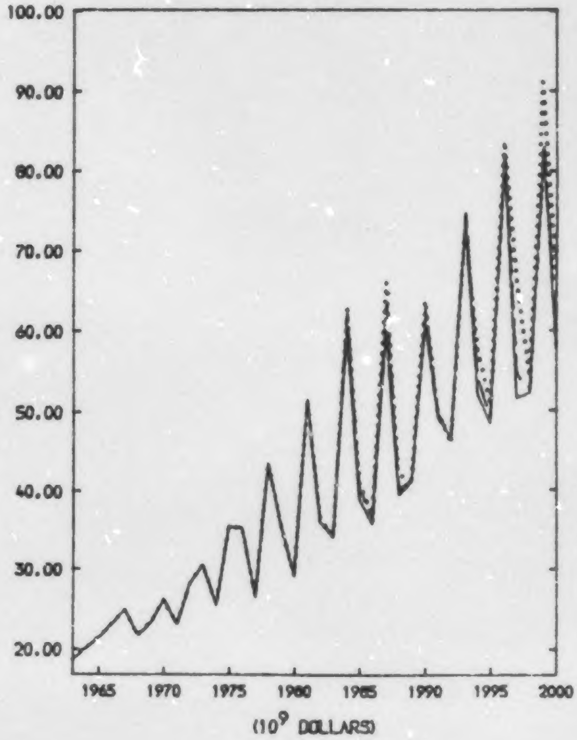
53-ELECTRIC INDUSTRIAL EQUIPMENT



54-HOUSEHOLD APPLIANCES

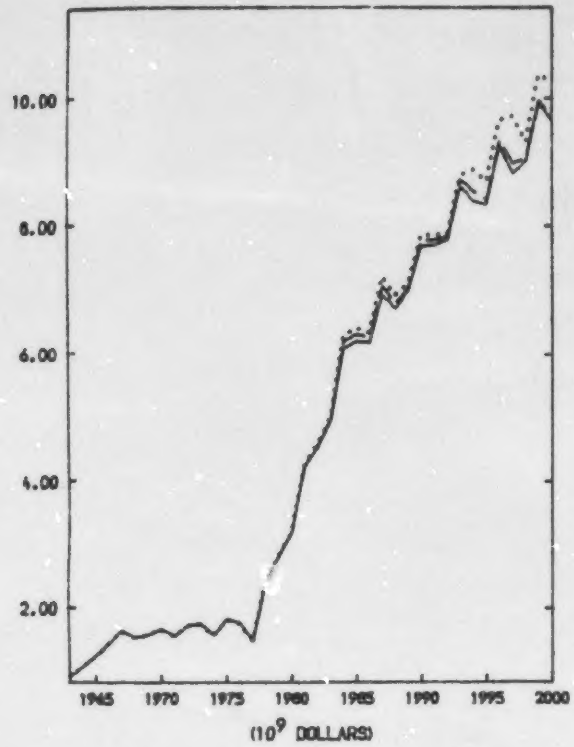


55-ELECTRIC LIGHTING AND WIRING EQUIP.

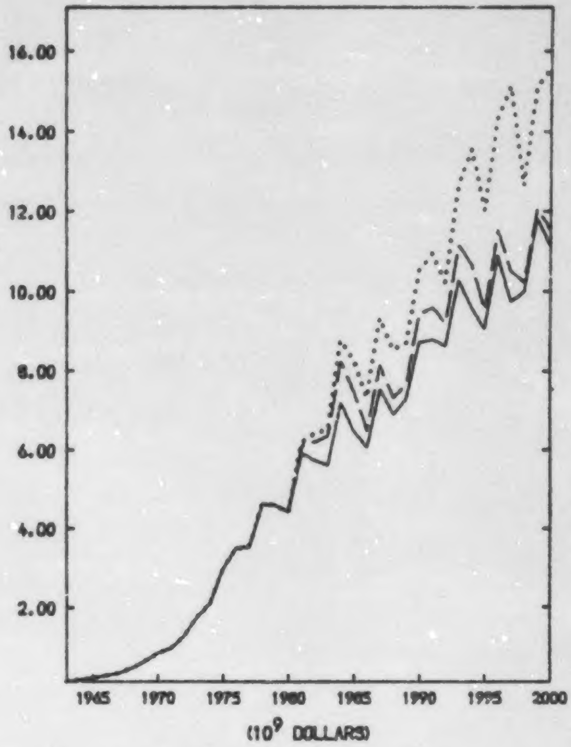


56-RADIO, TV AND COMMUNICATIONS EQUIPMENT

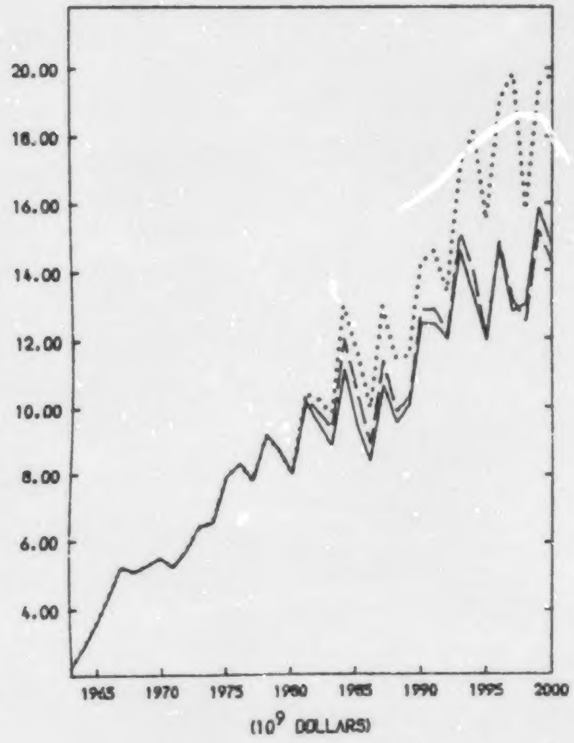
C. OUTPUT BY SECTOR



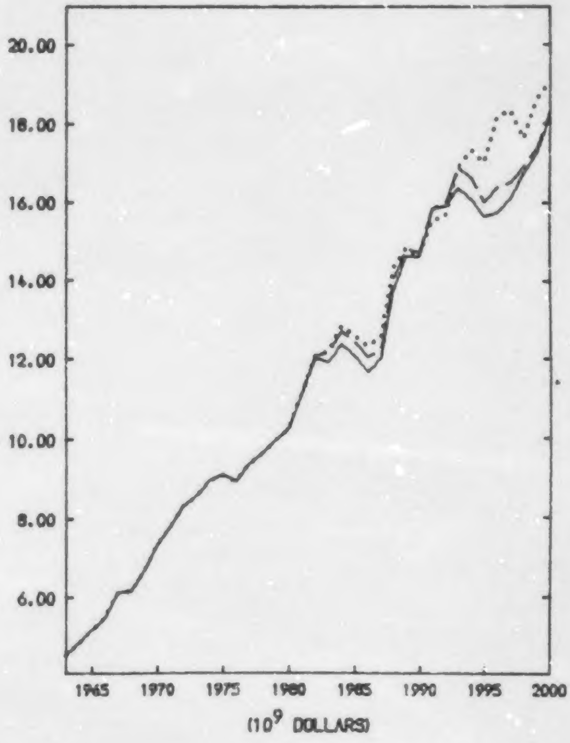
57-ELECTRON TUBES



58-SEMICONDUCTORS AND RELATED DEVICES

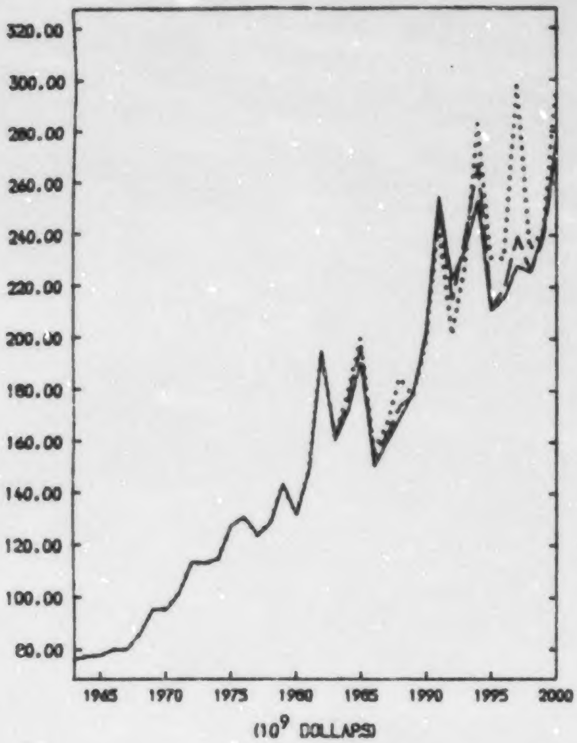


59-ELECTRONIC COMPONENTS, NEC

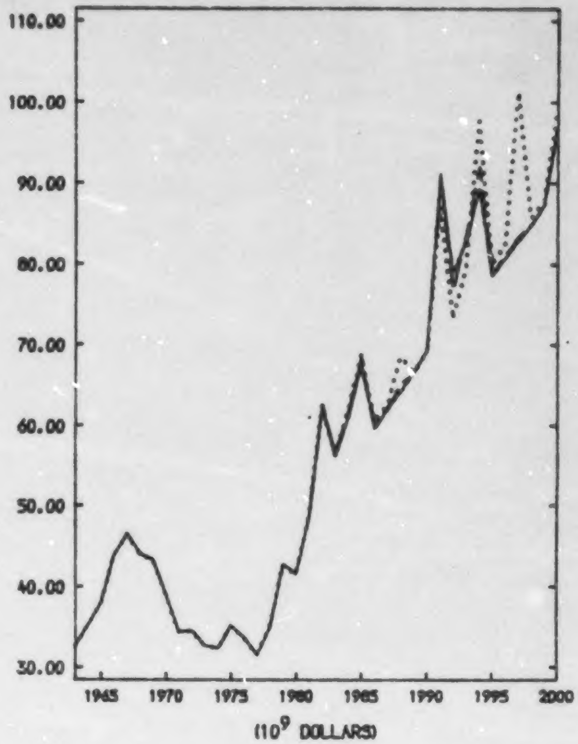


60-MISC ELECTRIC. MACHINERY AND SUPPLIES

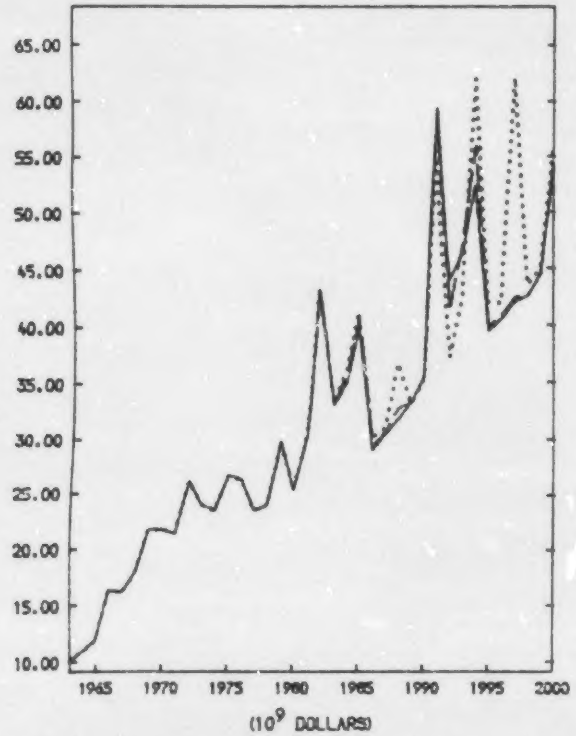
C. OUTPUT BY SECTOR



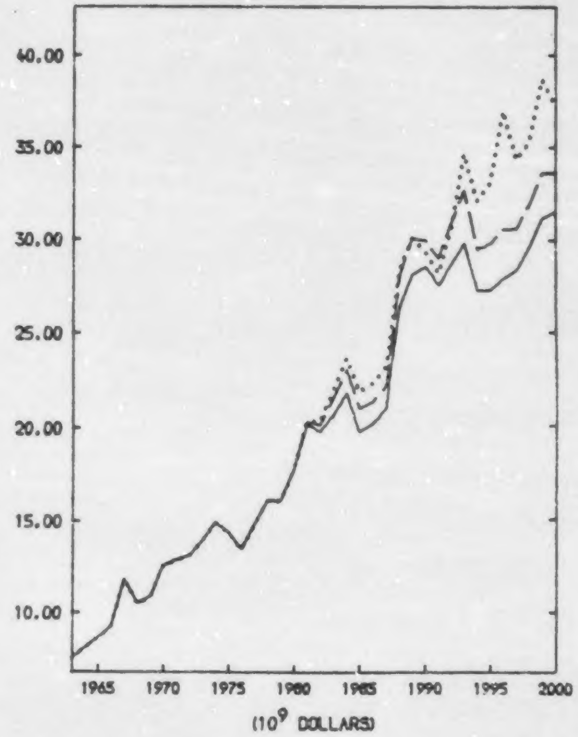
61-MOTOR VEHICLES AND EQUIPMENT



62-AIRCRAFT AND PARTS

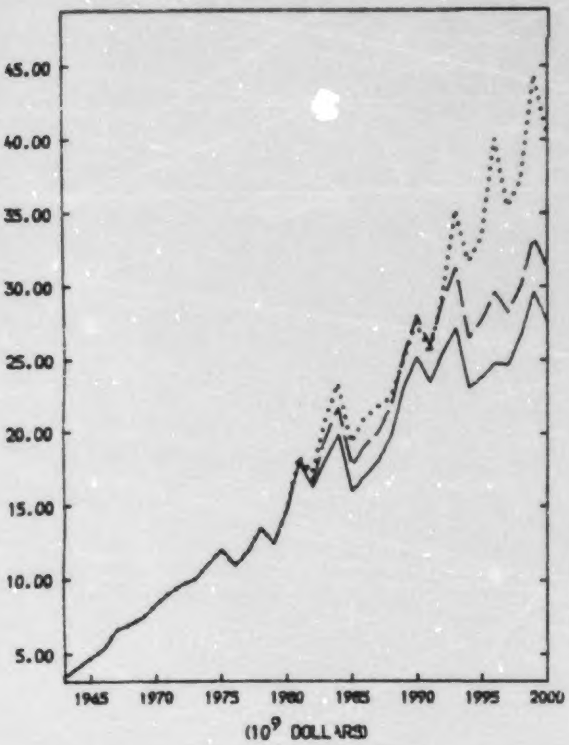


63-OTHER TRANSPORTATION EQUIPMENT

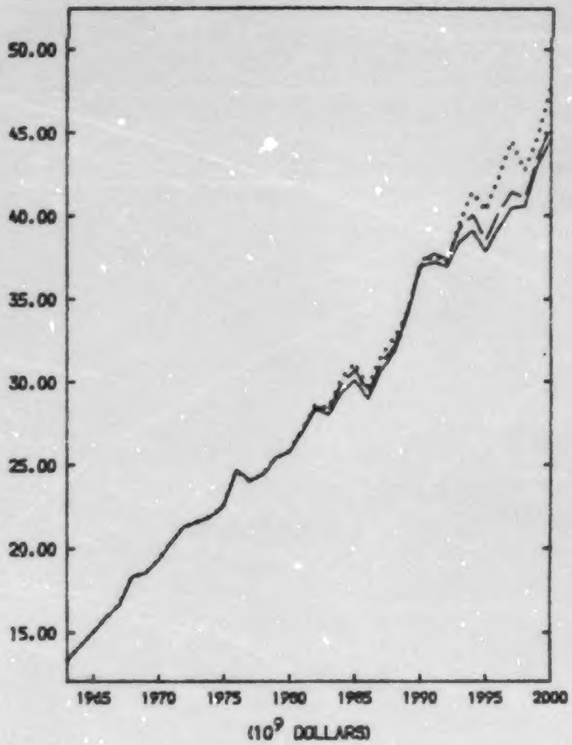


64-SCIENTIFIC AND CONTROL INSTRUMENTS

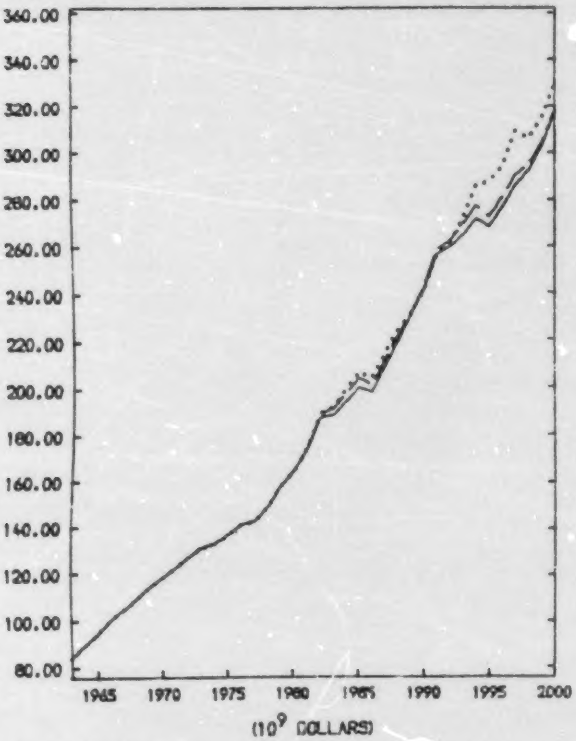
C. OUTPUT BY SECTOR



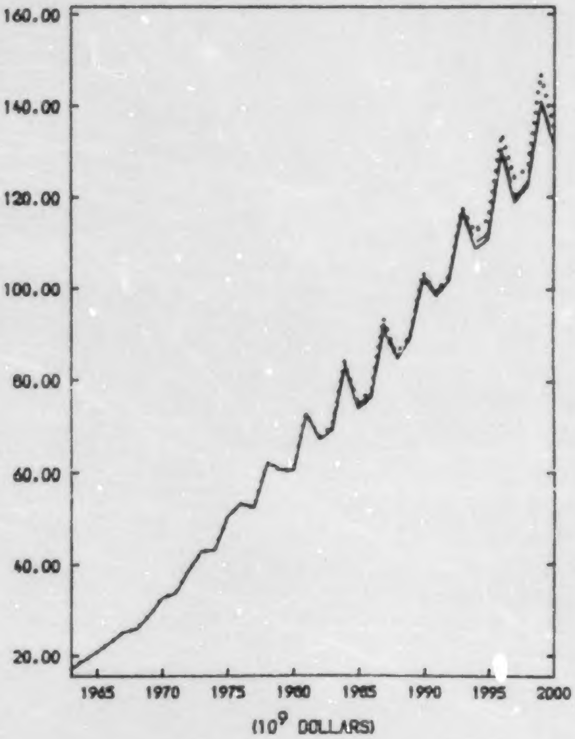
65-OPTICAL AND PHOTOGRAPHIC EQUIPMENT



66-MISCELLANEOUS MANUFACTURING

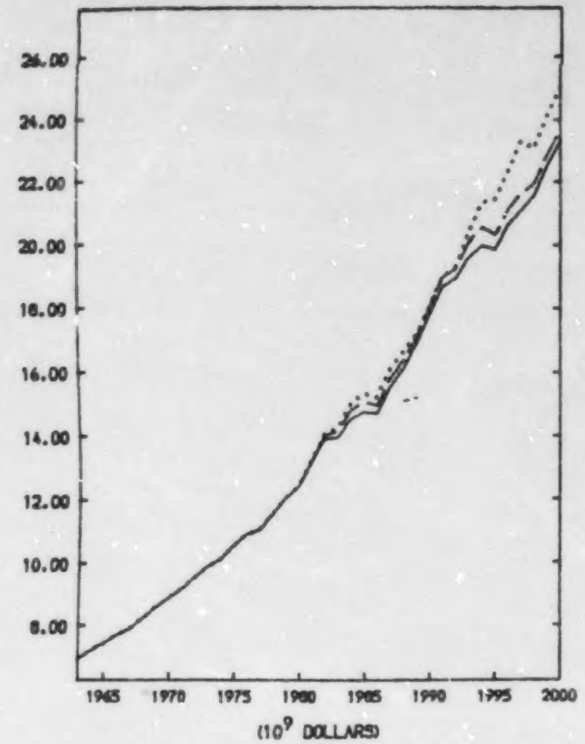


67-TRANSPORTATION AND WAREHOUSING

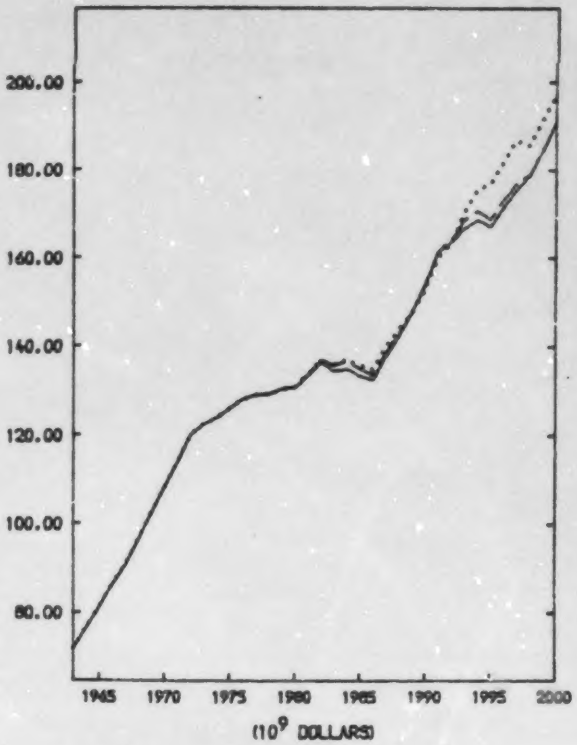


68-COMMUNICATIONS, EXCEPT RADIO AND TV

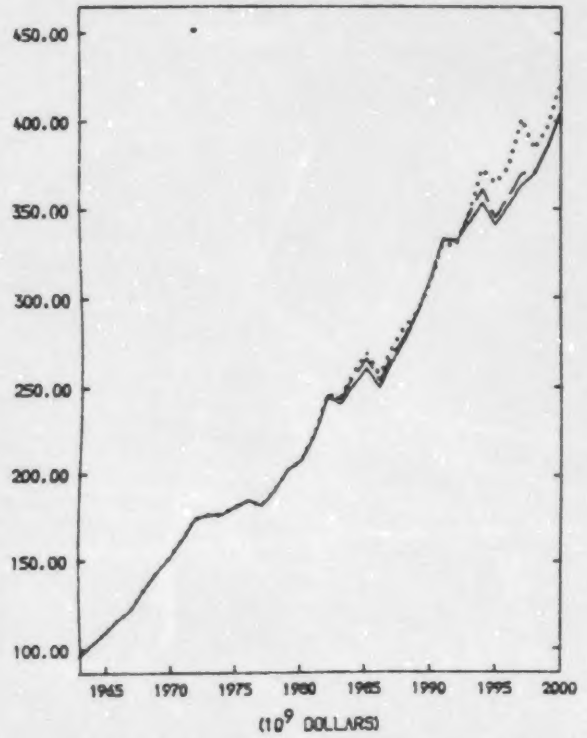
C. OUTPUT BY SECTOR



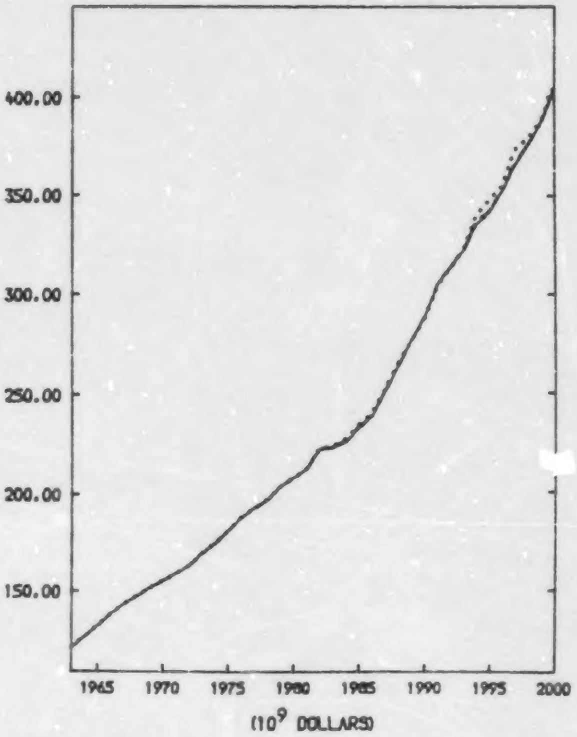
69-RADIO AND TV BROADCASTING



70-ELECTRIC, GAS AND WATER SERVICES

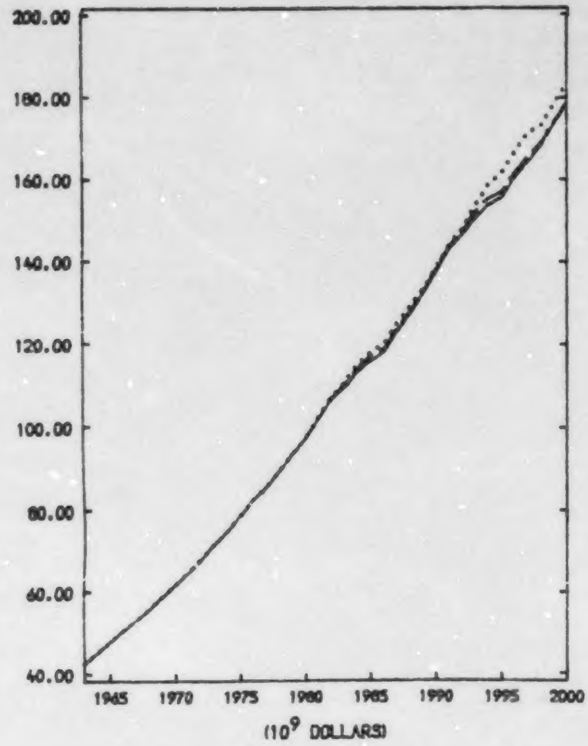


71-WHOLESALE TRADE

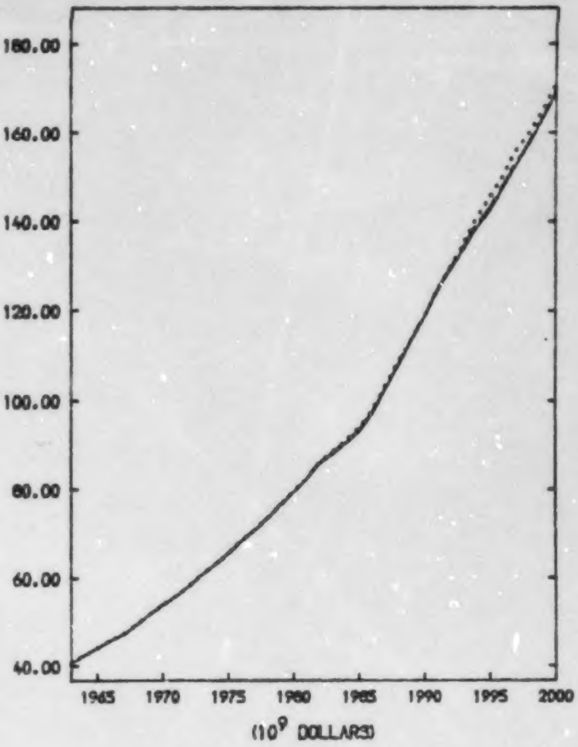


72-RETAIL TRADE

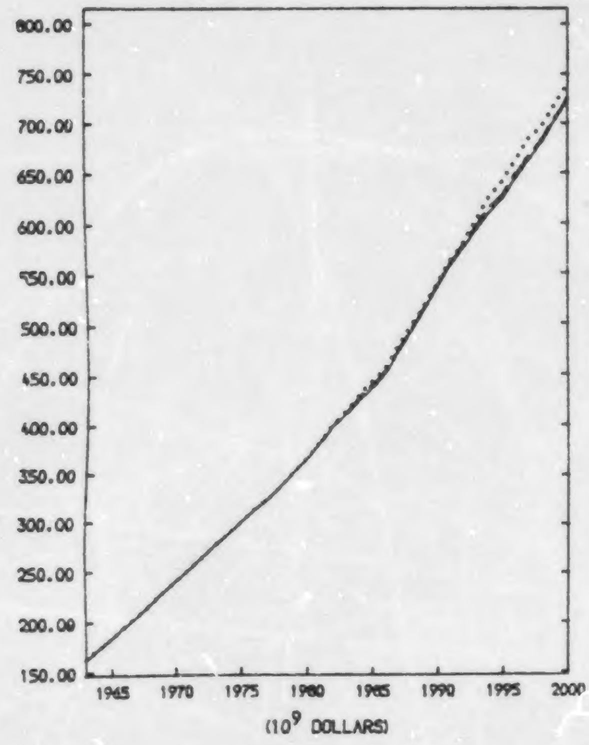
C. OUTPUT BY SECTOR



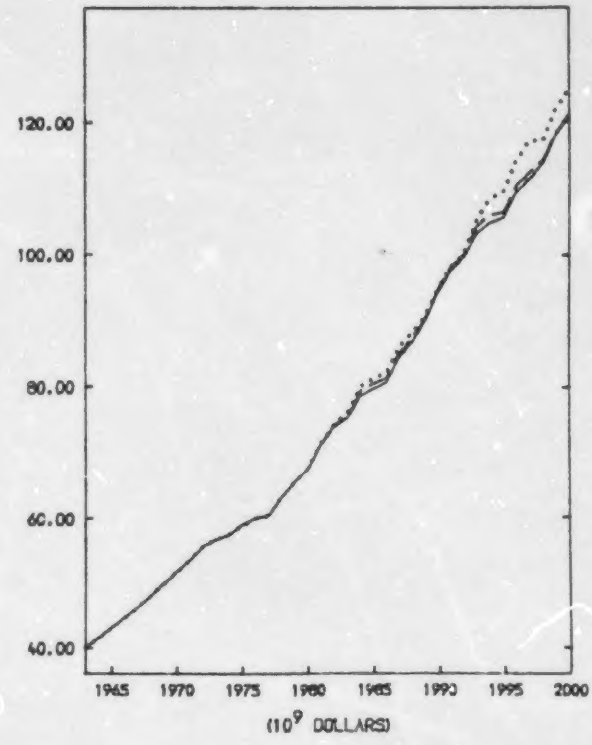
73-FINANCE



74-INSURANCE

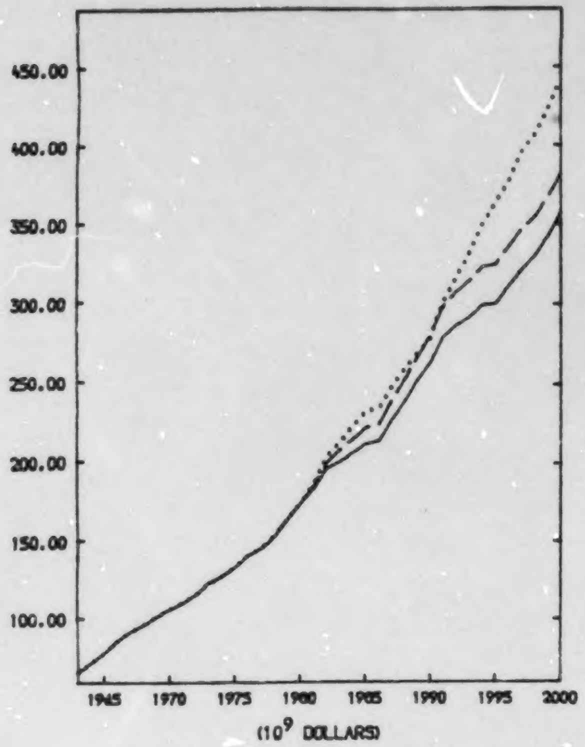


75-REAL ESTATE AND RENTAL

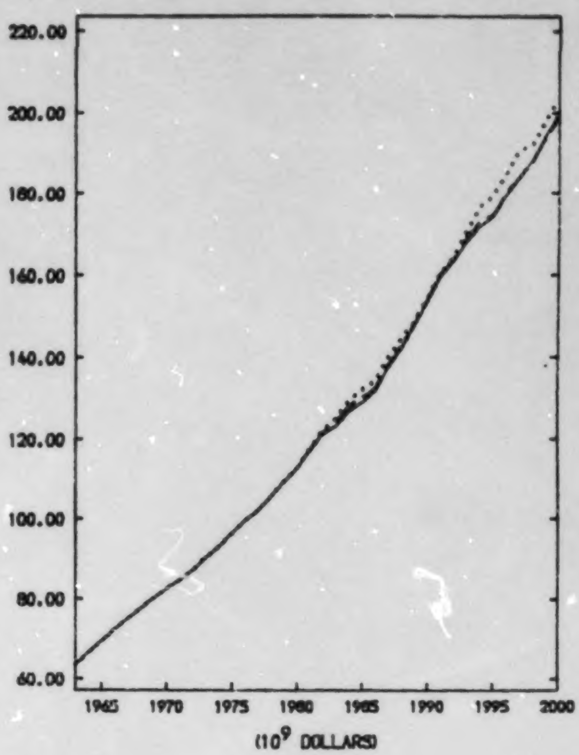


76-HOTELS, PERSONAL AND REPAIR SERVICES

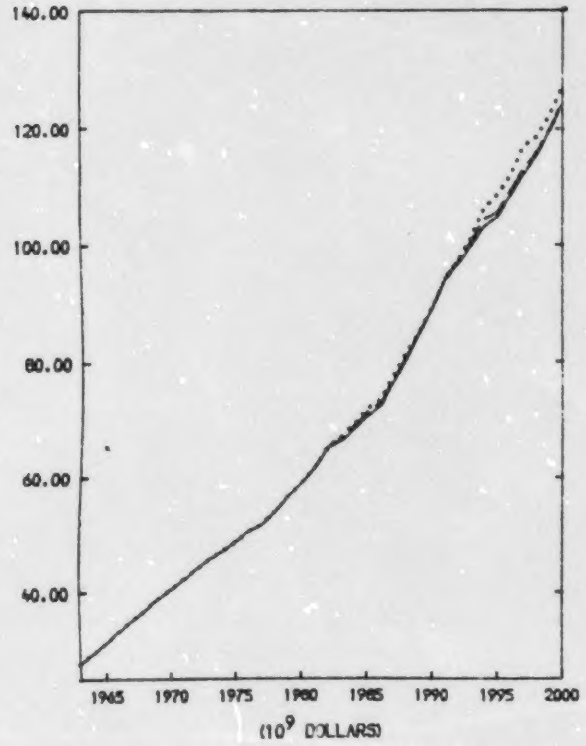
C. OUTPUT BY SECTOR



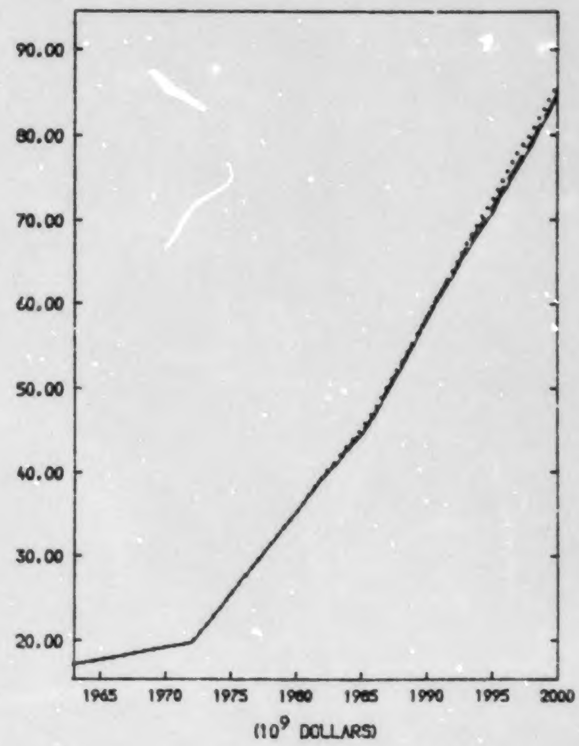
77-BUSINESS SERVICES



78-EATING AND DRINKING PLACES

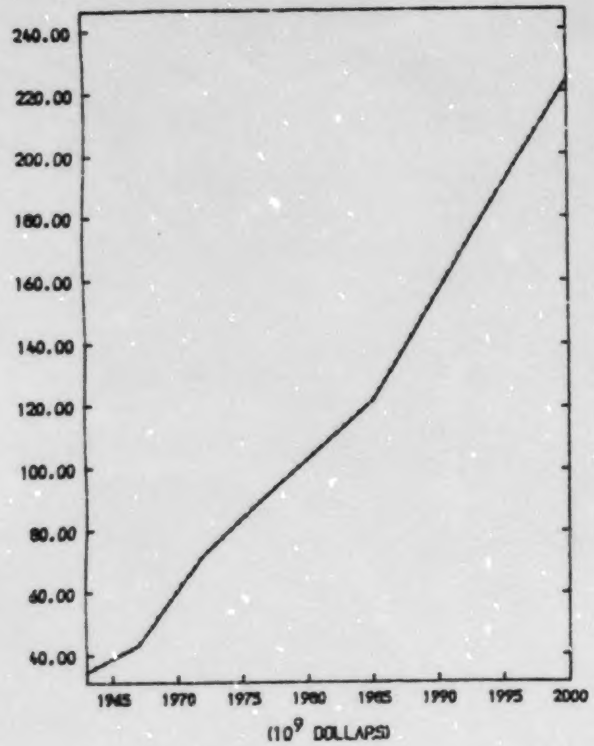


79-AUTOMOBILE REPAIR SERVICES

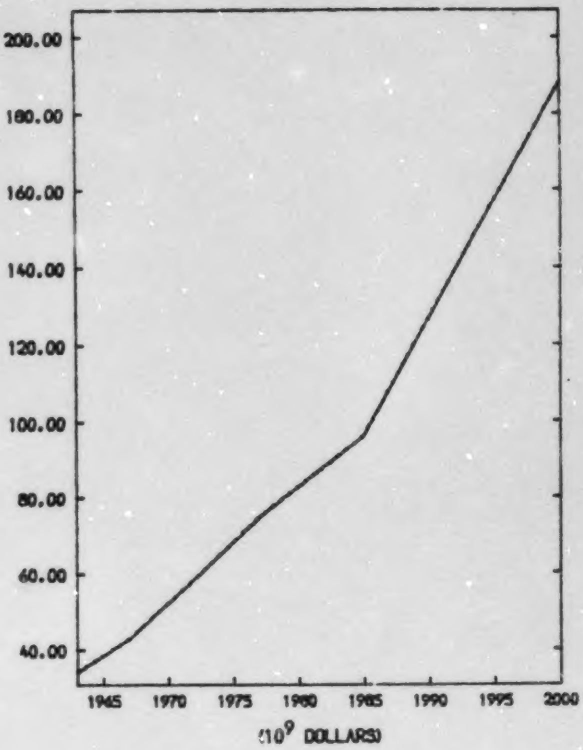


80-AMUSEMENTS

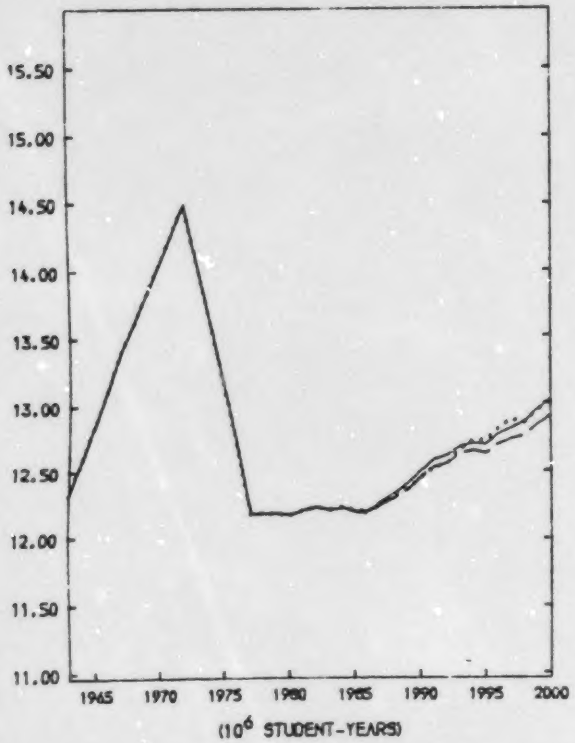
C. OUTPUT BY SECTOR



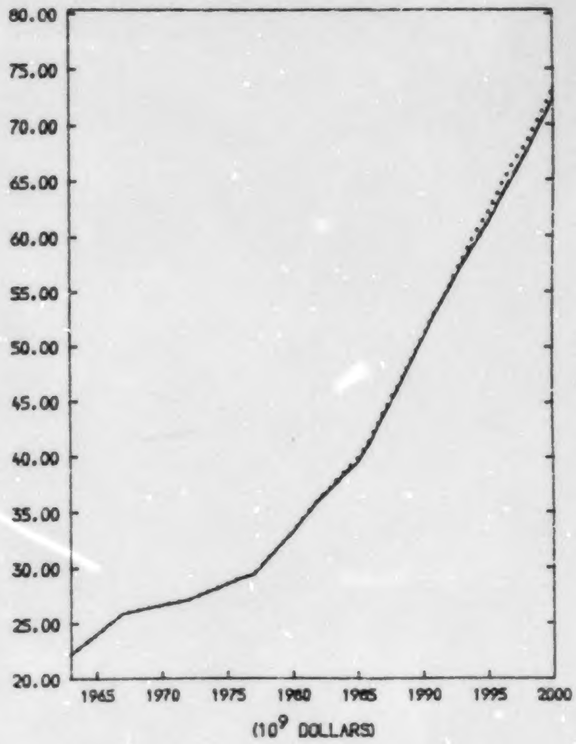
81-HOSPITALS



82-HEALTH SERVICES, EXCLUDING HOSPITALS

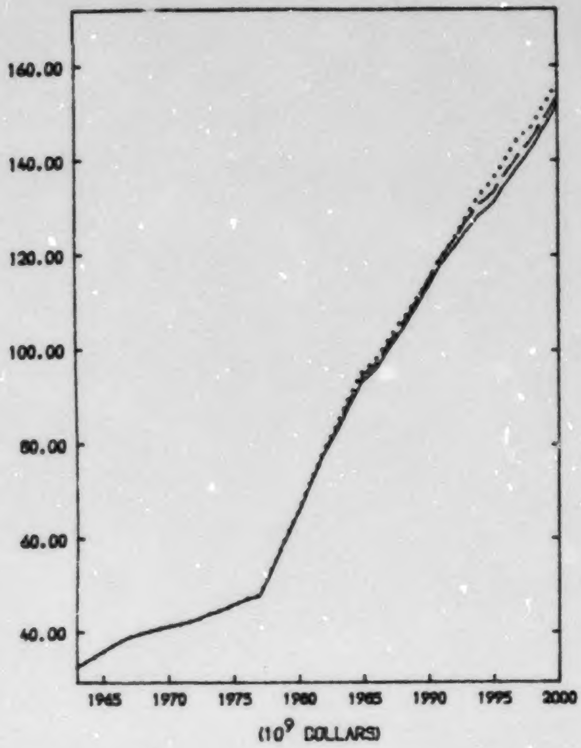


83-EDUCATIONAL SERVICES (PRIVATE)

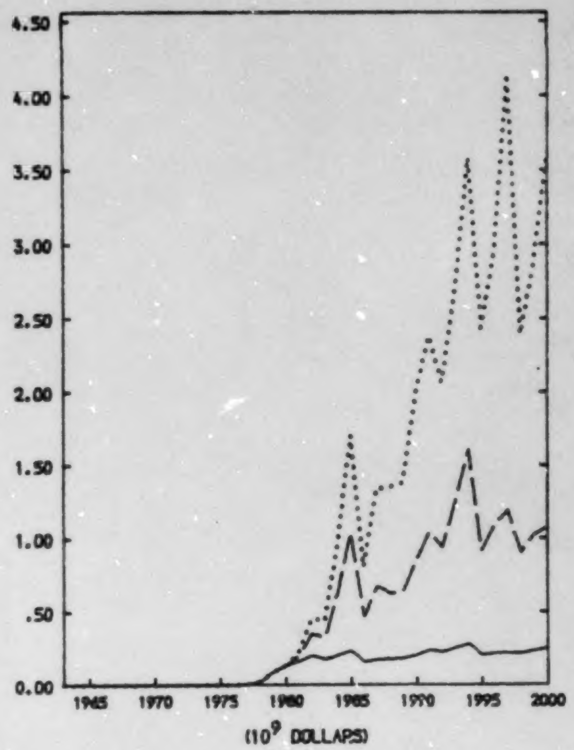


84-NONPROFIT ORGANIZATIONS

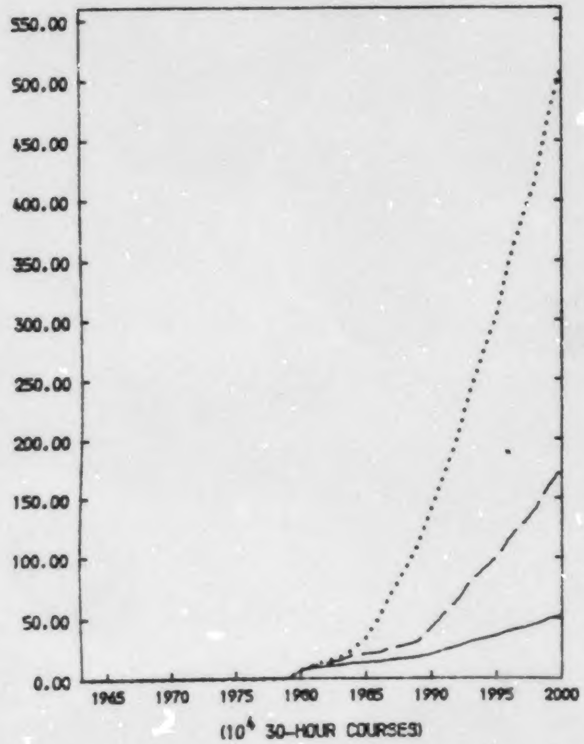
C. OUTPUT BY SECTOR



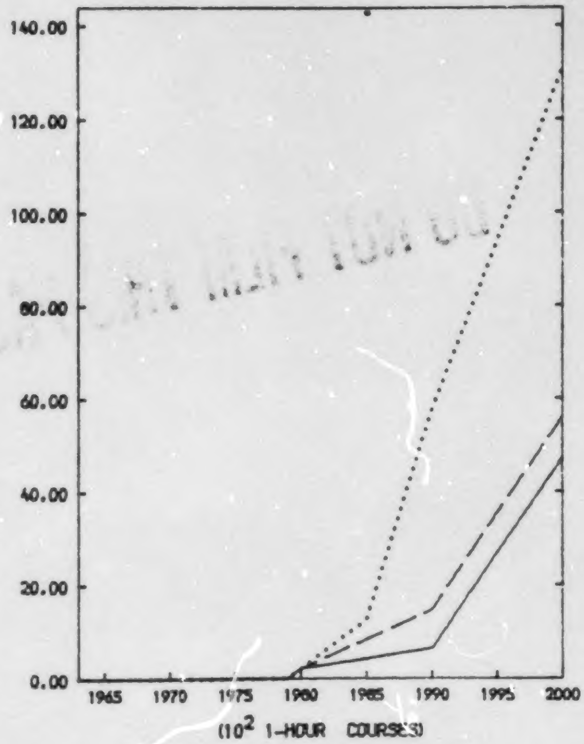
85-GOVERNMENT ENTERPRISES



86-ROBOTICS MANUFACTURING

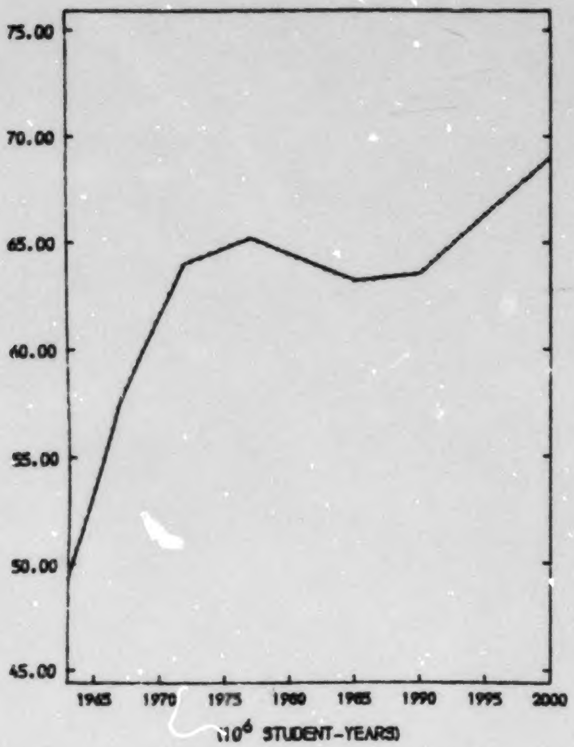


87-INSTRUCTIONAL TV

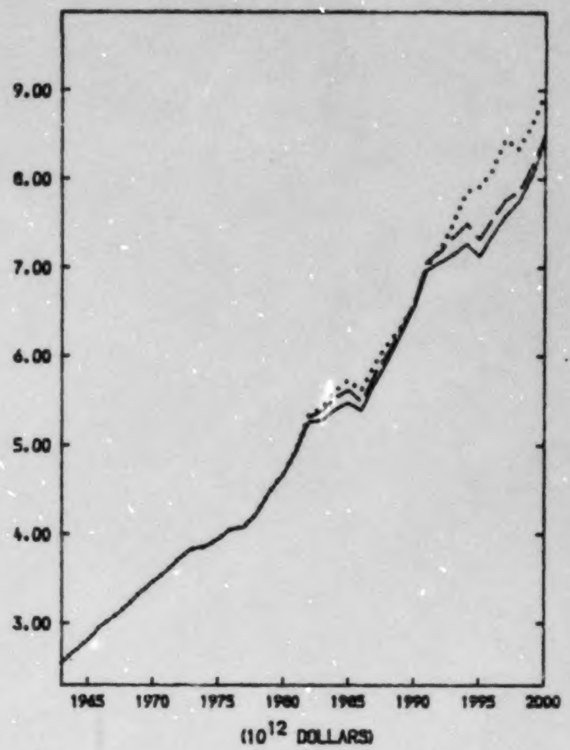


88-COMPUTER-BASED INSTRUCTION

C. OUTPUT BY SECTOR

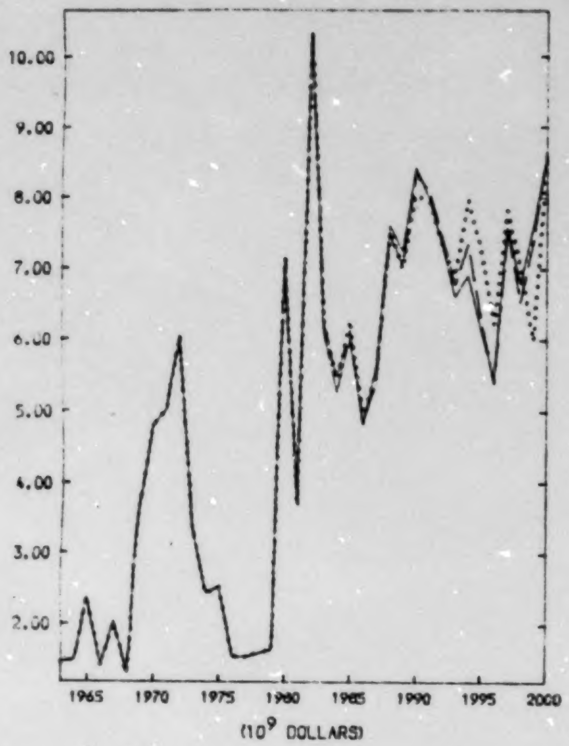


89-PUBLIC EDUCATION

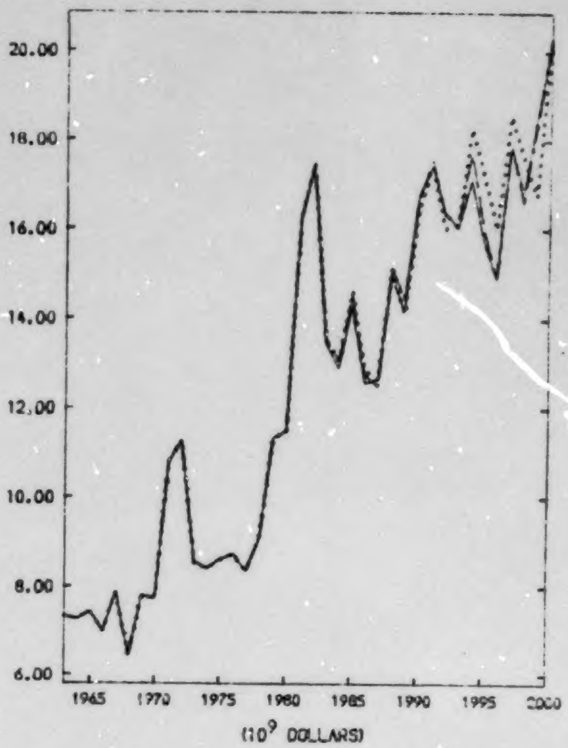


90-TOTAL

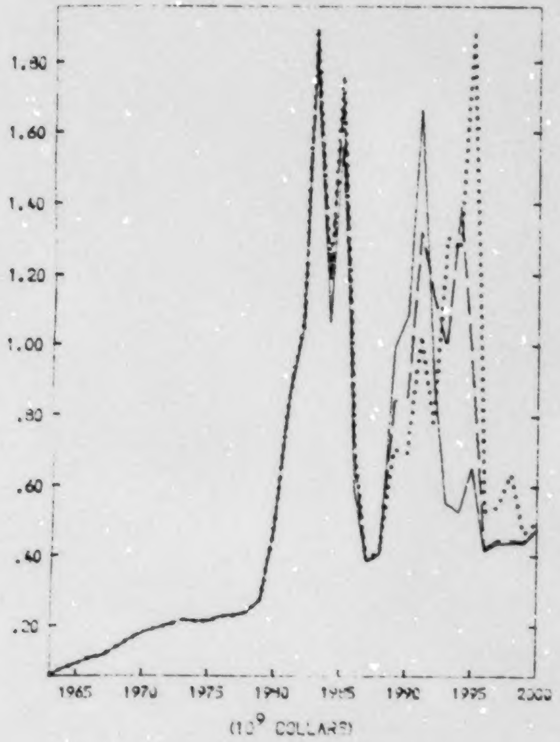
D. GROSS INVESTMENT BY SECTOR



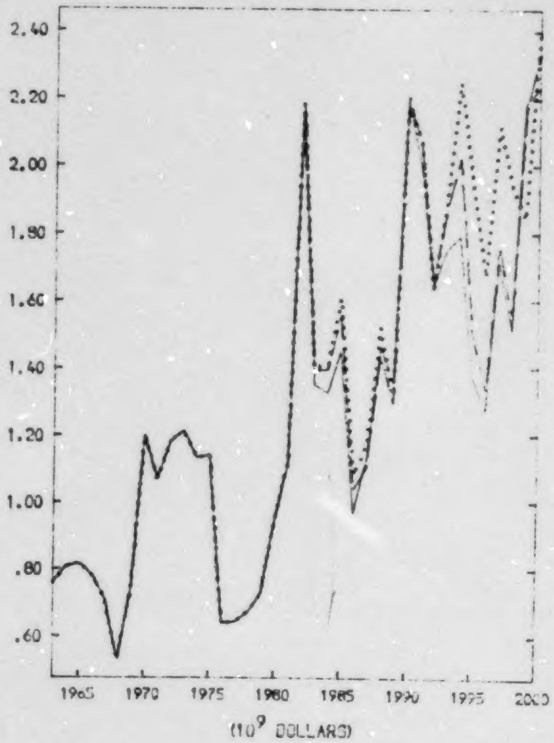
1-LIVESTOCK AND LIVESTOCK PRODUCTS



2-OTHER AGRICULTURAL PRODUCTS

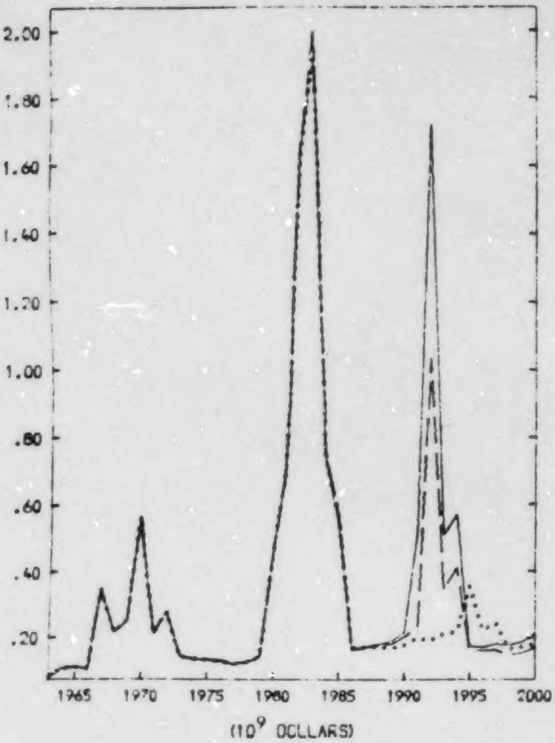


3-FORESTRY AND FISHERY PRODUCTS

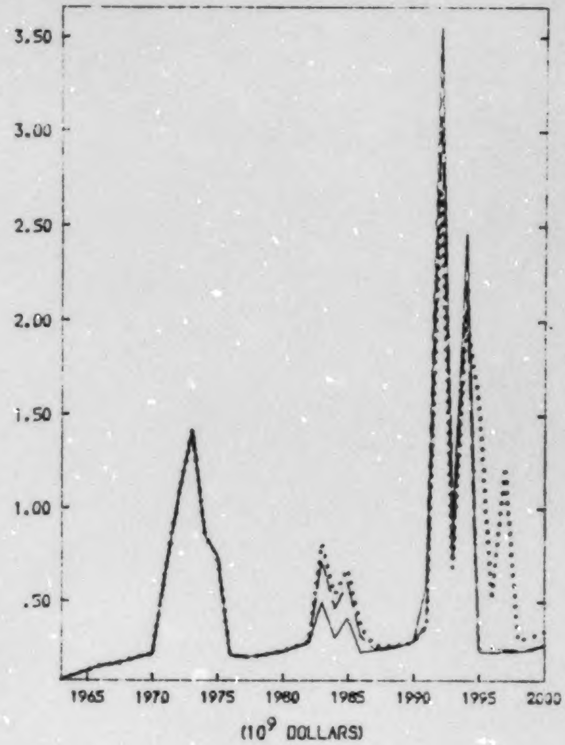


4-AGR, FORESTRY, AND FISHERY SERVICES

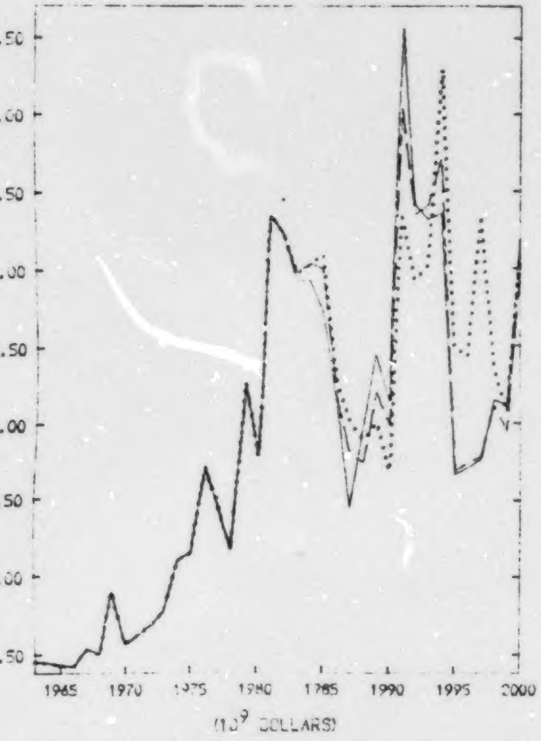
D. GROSS INVESTMENT BY SECTOR



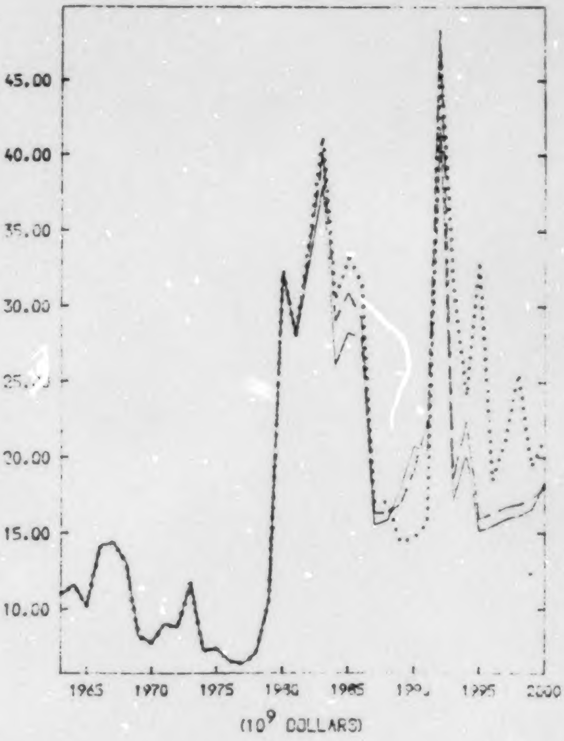
5-IRON AND FERROALLOY ORES MINING



6-NONFERROUS METAL ORES MINING

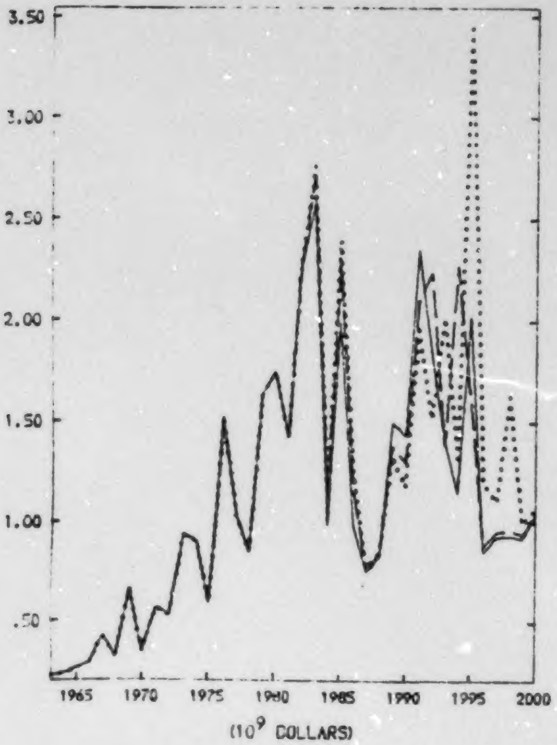


7-COAL MINING

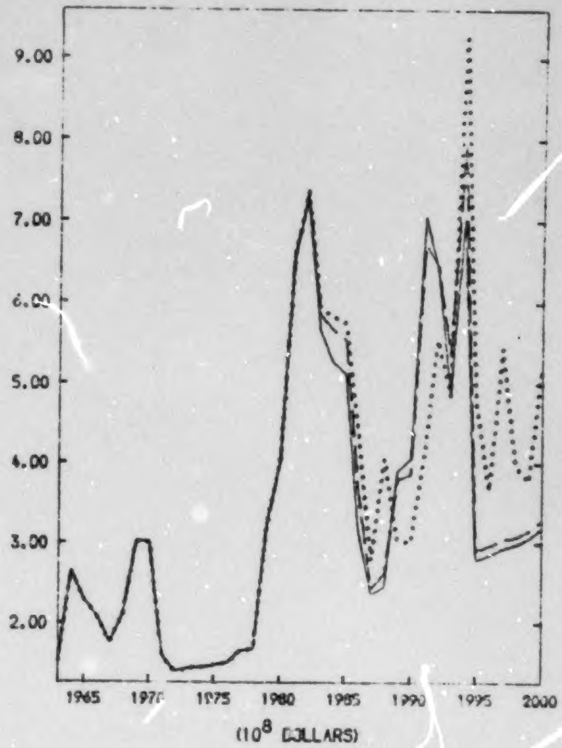


8-CRUDE PETROLEUM AND NATURAL GAS

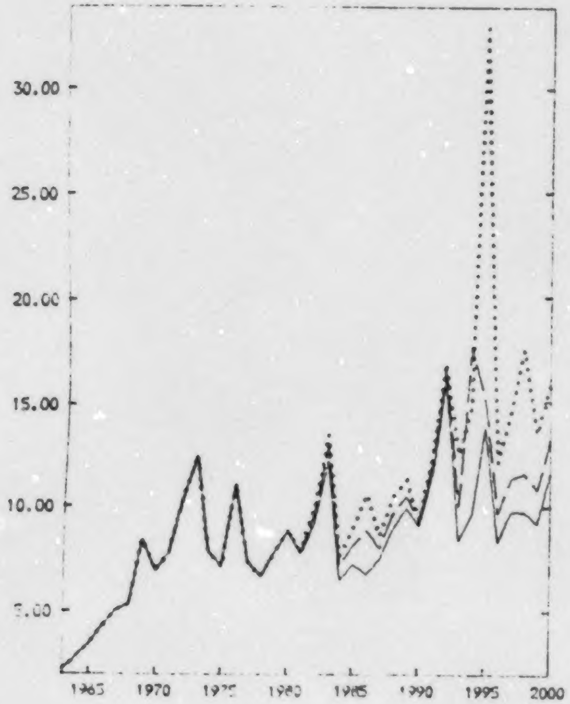
D. GROSS INVESTMENT BY SECTOR



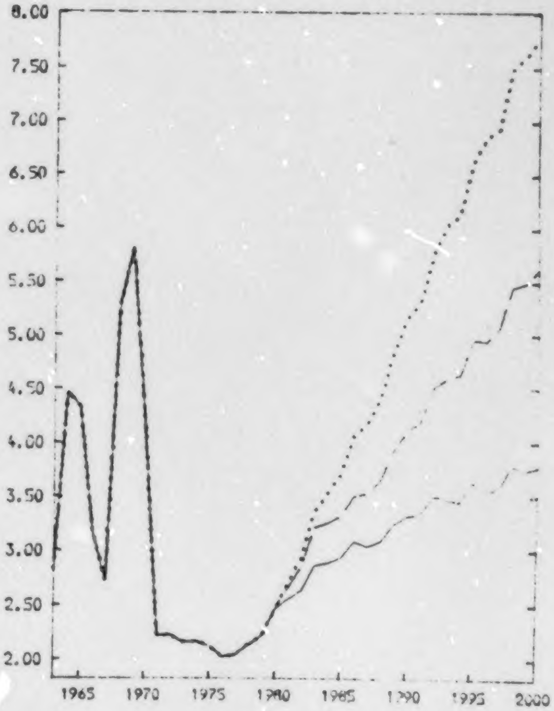
9-STONE AND CLAY MINING AND QUARRYING



10-CHEM AND FERTILIZER MINERAL MINING

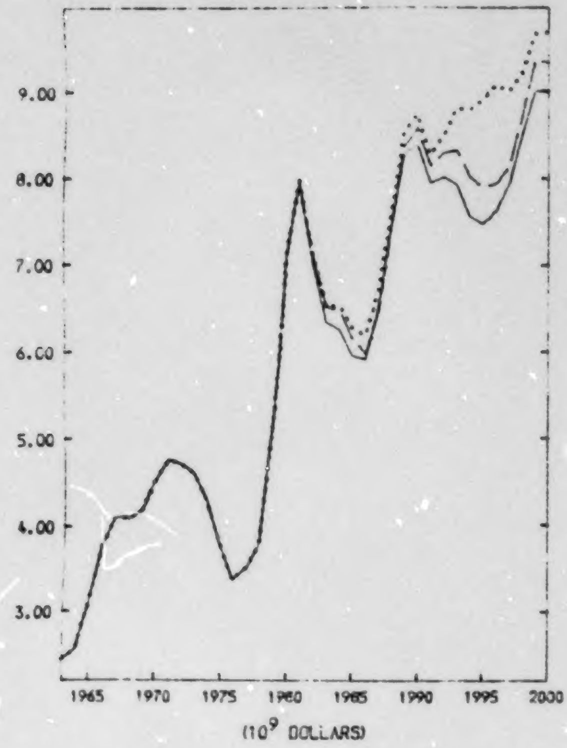


11-CONSTRUCTION

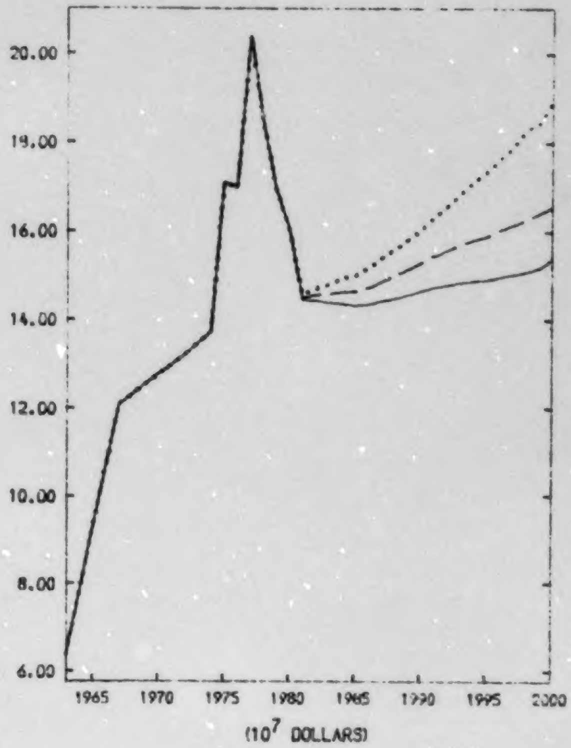


12-ORDNANCE AND ACCESSORIES

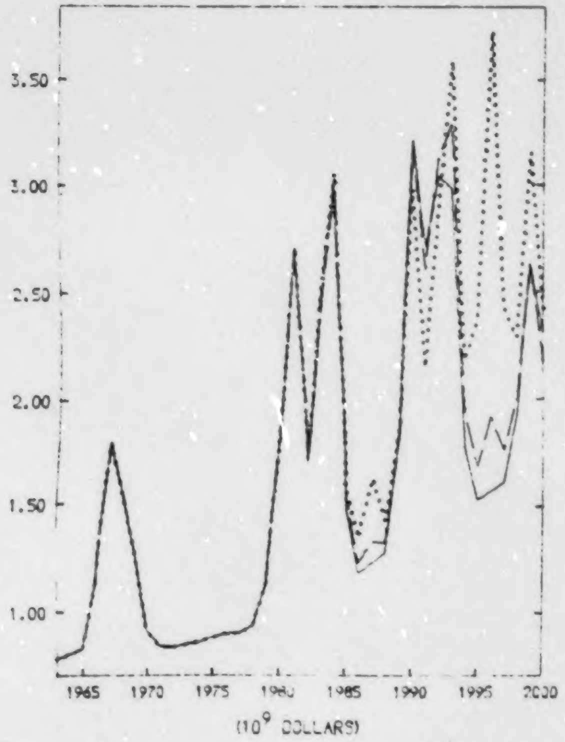
D. GROSS INVESTMENT BY SECTOR



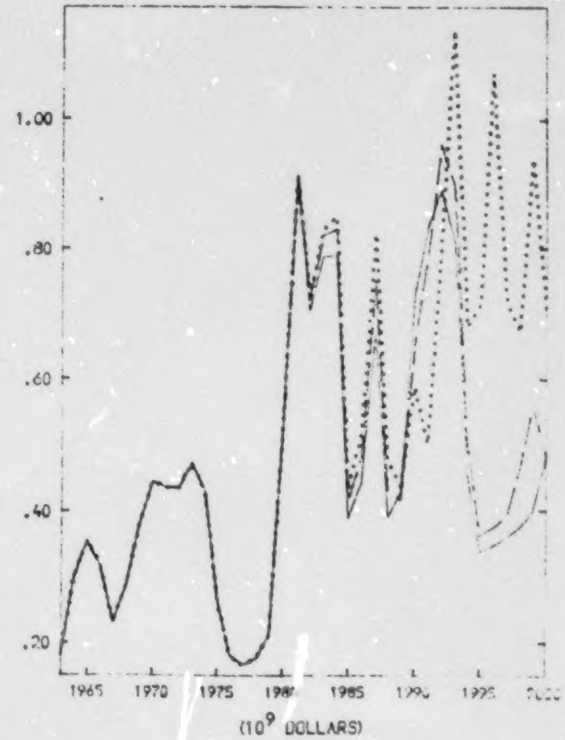
13-FOOD AND KINDRED PRODUCTS



14-TOBACCO

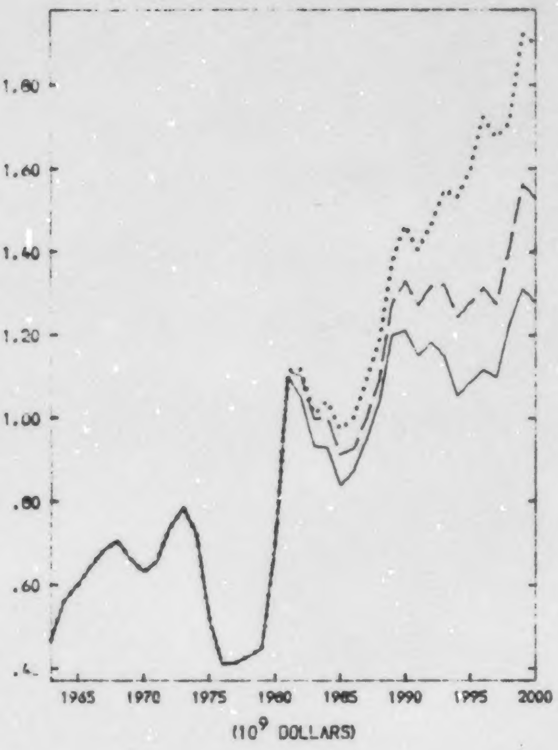


15-FABRICS, YARN AND THREAD MILLS

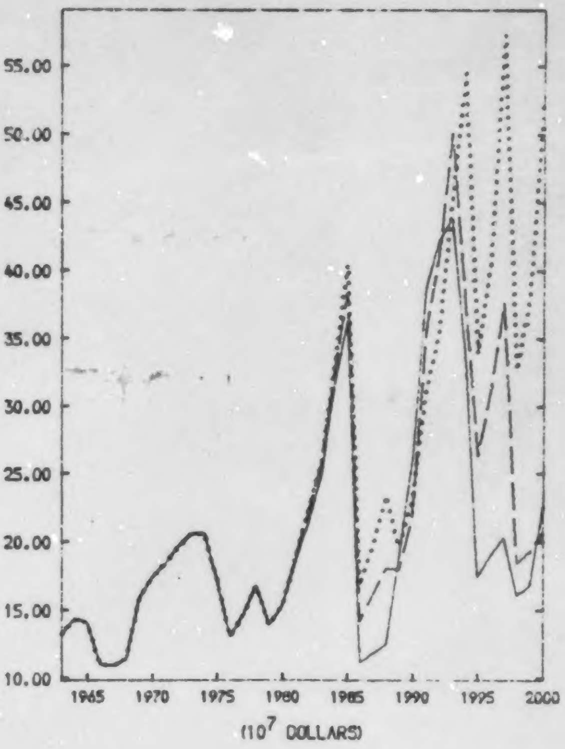


16-MISC TEXTILE GOODS AND FLOOR COVERING

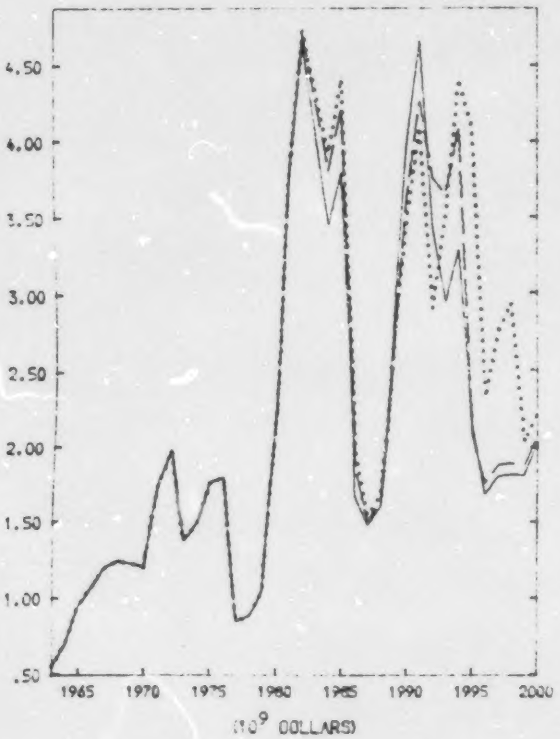
D. GROSS INVESTMENT BY SECTOR



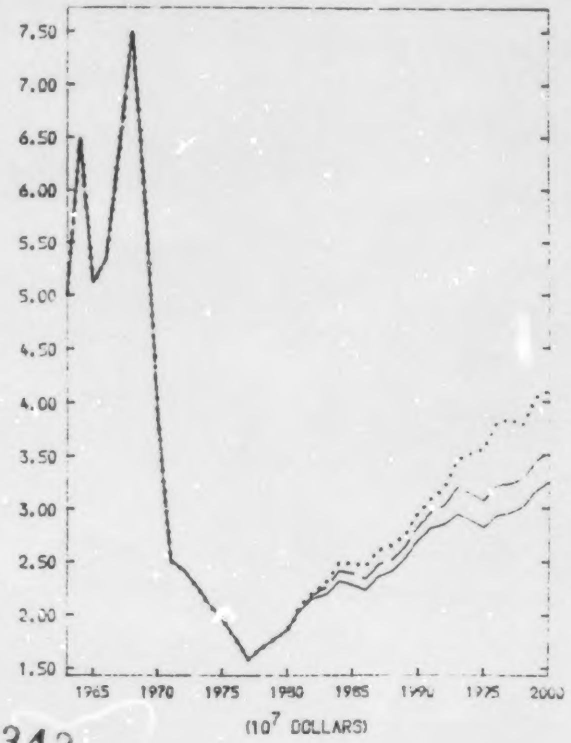
17-APPAREL



18-MISC FABRICATED TEXTILE PRODUCTS

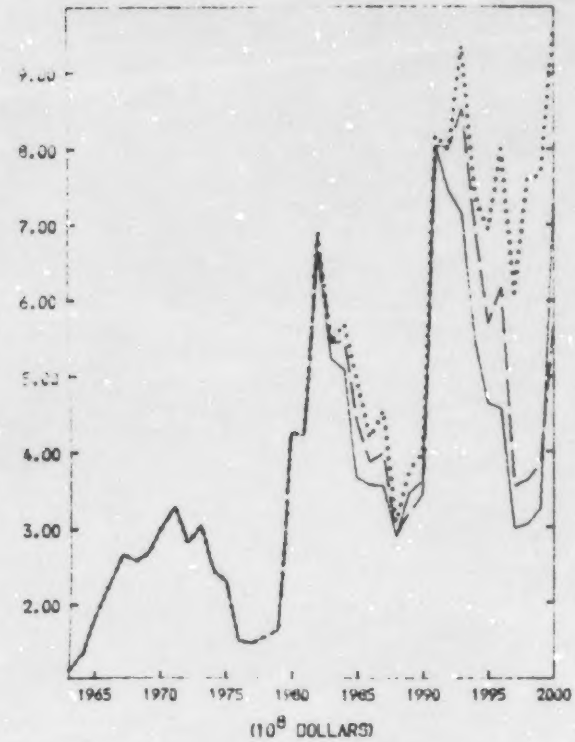


19-LUMBER AND WOOD PROD, EXC CONTAINERS

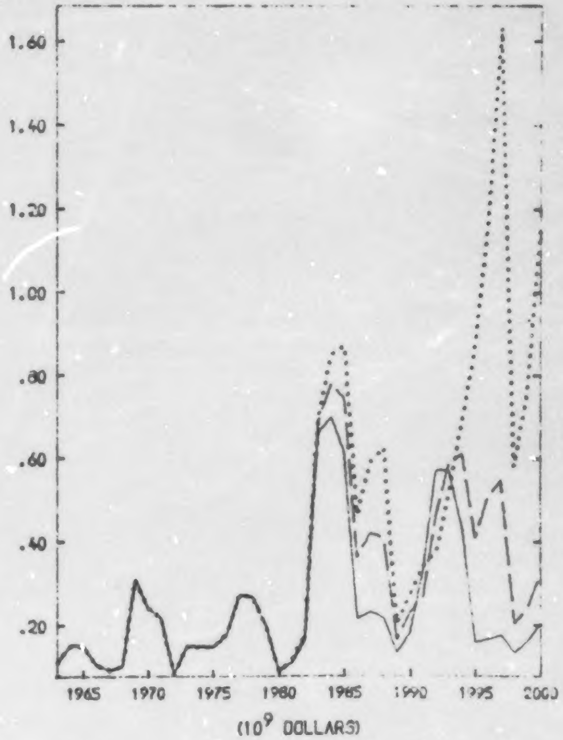


20-WOOD CONTAINERS

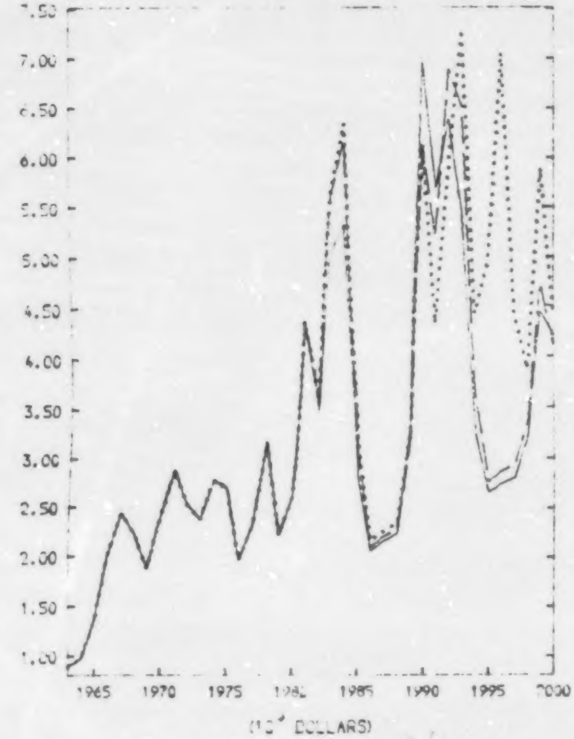
D. GROSS INVESTMENT BY SECTOR



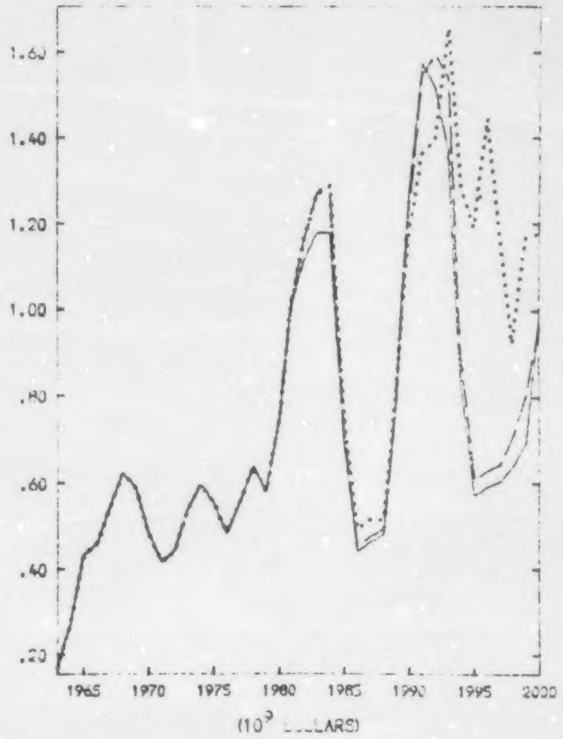
21-HOUSEHOLD FURNITURE



22-OTHER FURNITURE AND FIXTURES

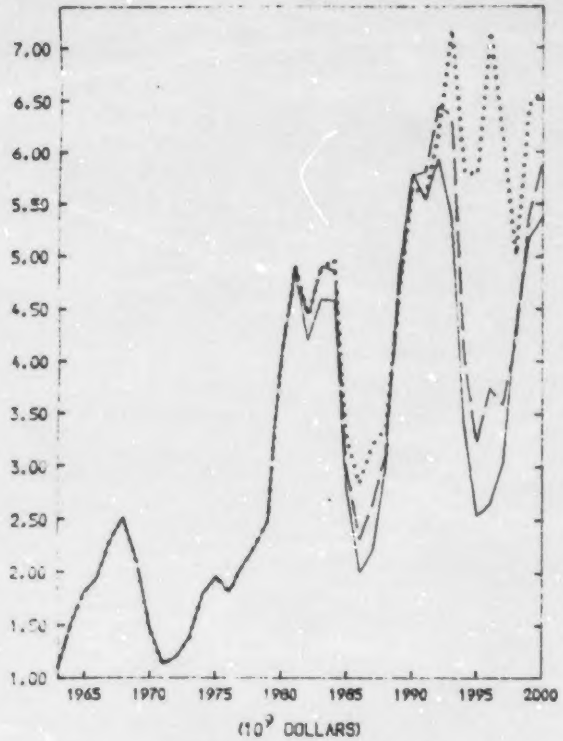


23-PAPER AND ALLIED PROD, EXC CONTAINERS

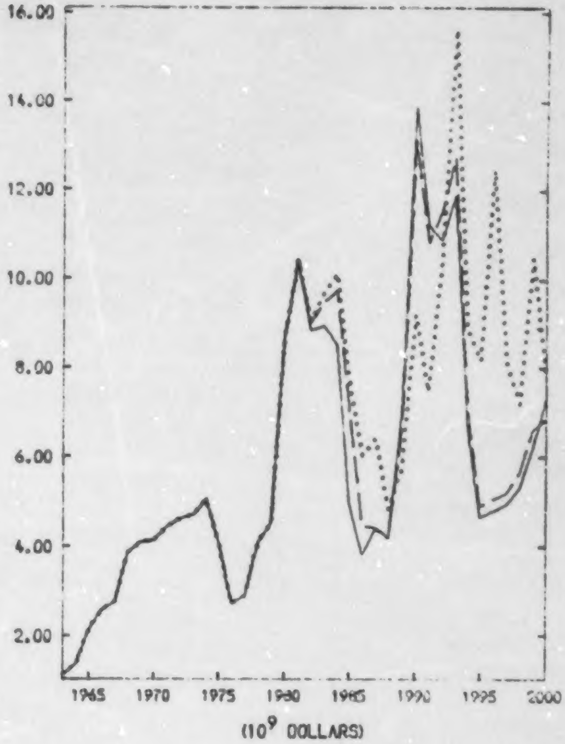


24-PAPERBOARD CONTAINERS AND BOXES

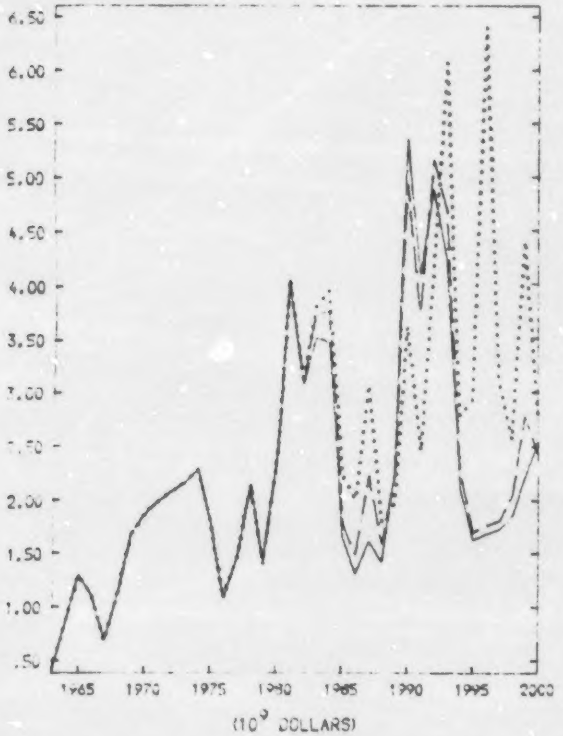
D. GROSS INVESTMENT BY SECTOR



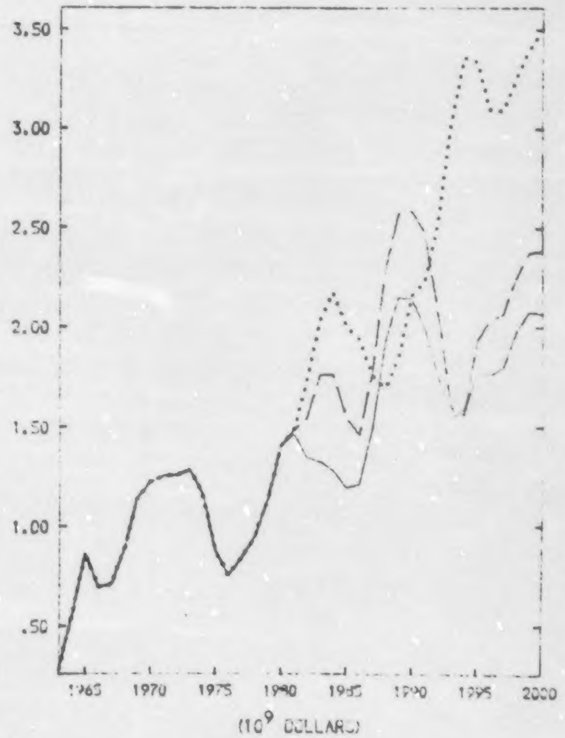
25-PRINTING AND PUBLISHING



26-CHEMICALS AND SELECTED CHEM PRODUCTS

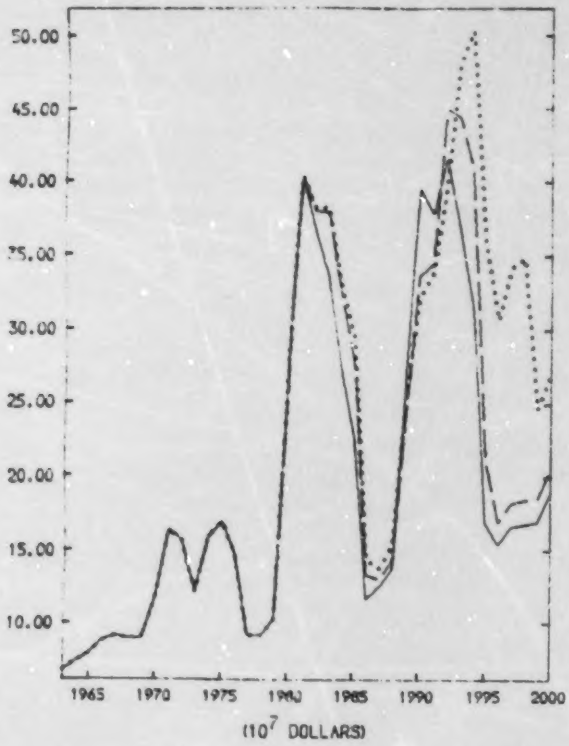


27-PLASTICS AND SYNTHETIC MATERIALS

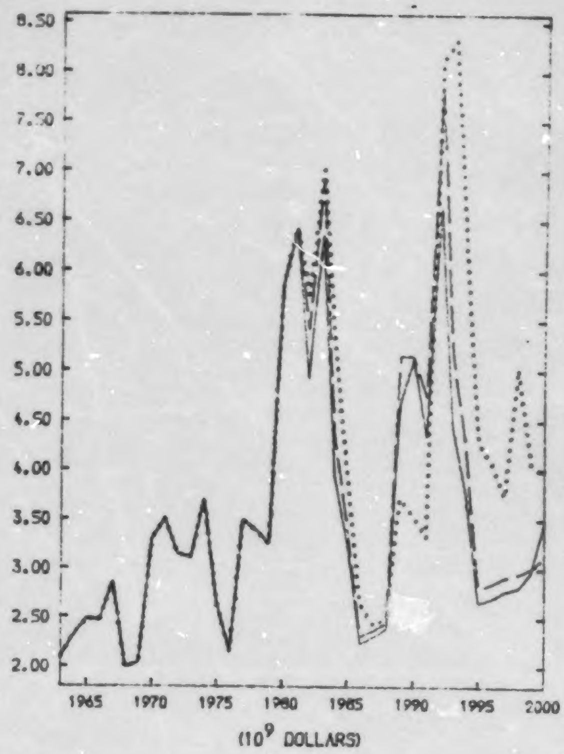


28-DRUGS, CLEANING AND TOILET PREPARATION

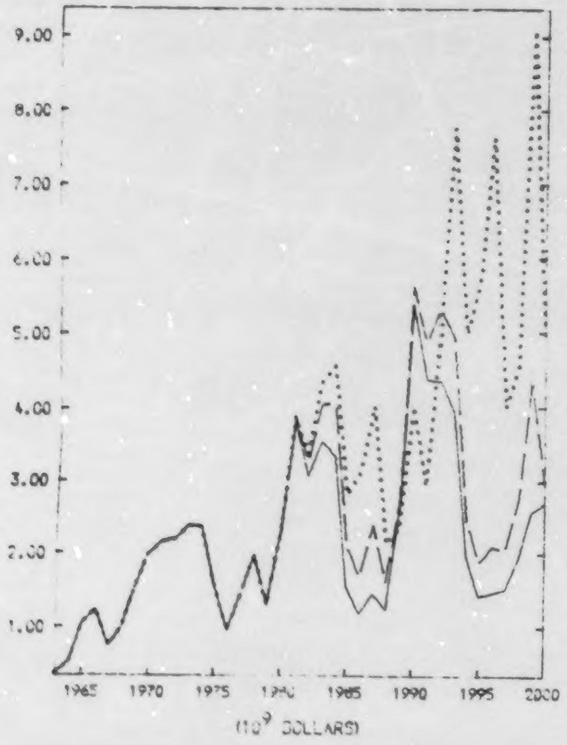
D. GROSS INVESTMENT BY SECTOR



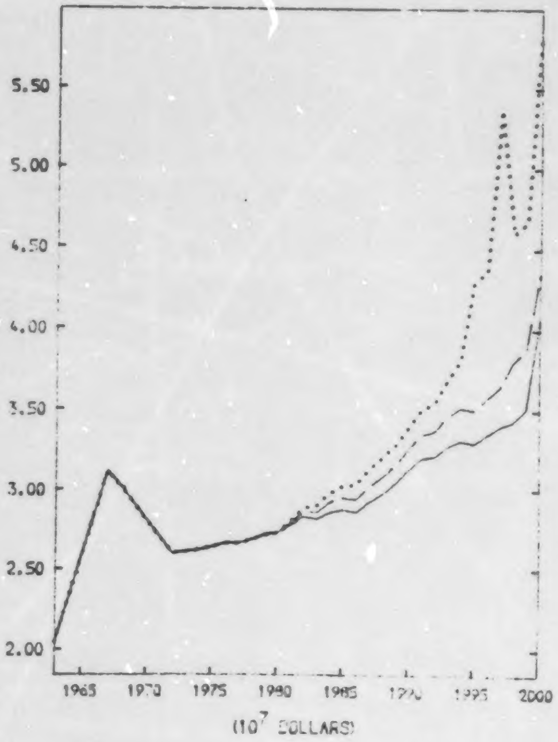
29-PAINTS AND ALLIED PRODUCTS



30-PETROLEUM REFINING AND ALLIED IND.

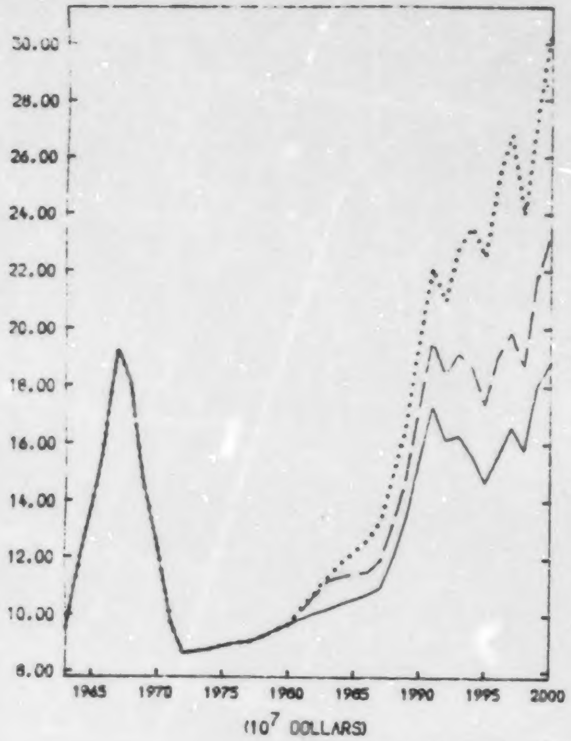


31-RUBBER AND MISC PLASTIC PRODUCTS

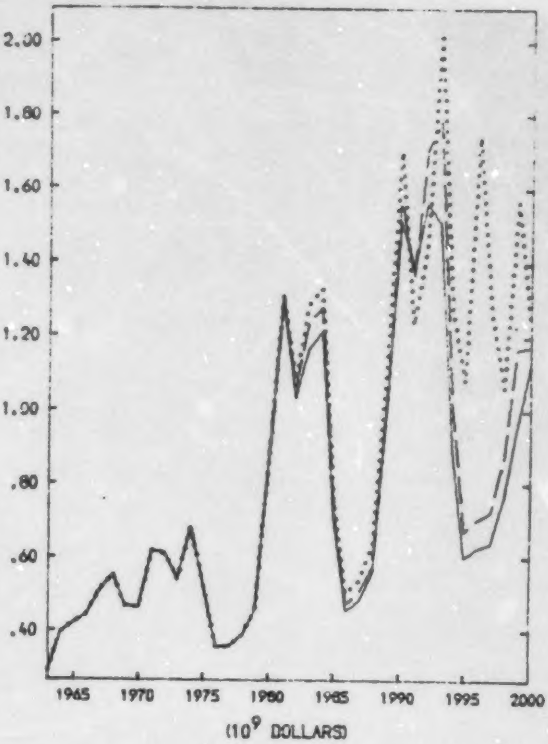


32-LEATHER TANNING AND FINISHING

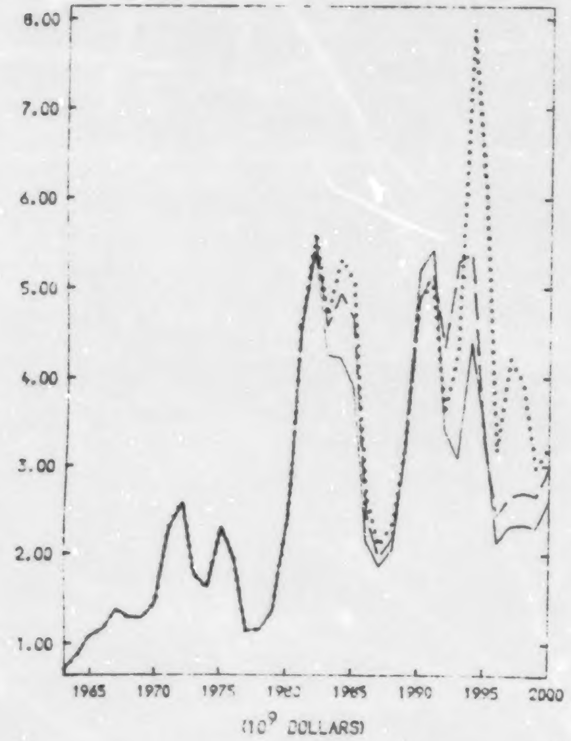
D. GROSS INVESTMENT BY SECTOR



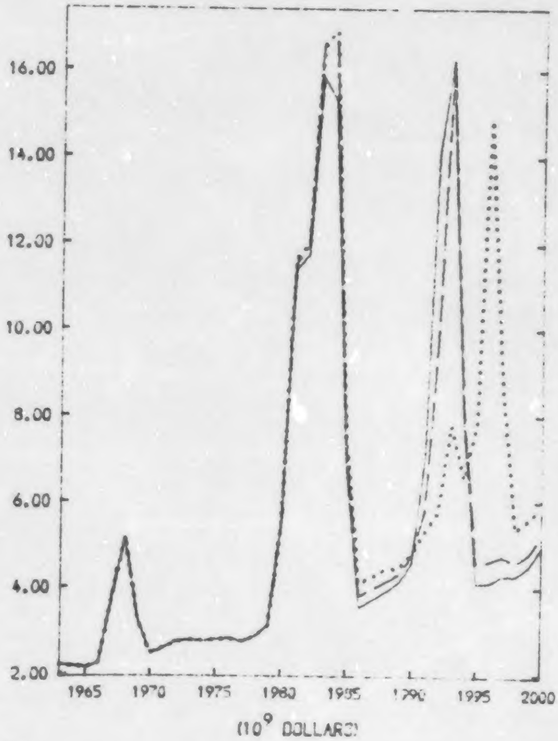
33-FOOTWEAR AND OTHER LEATHER PRODUCTS



34-GLASS AND GLASS PRODUCTS

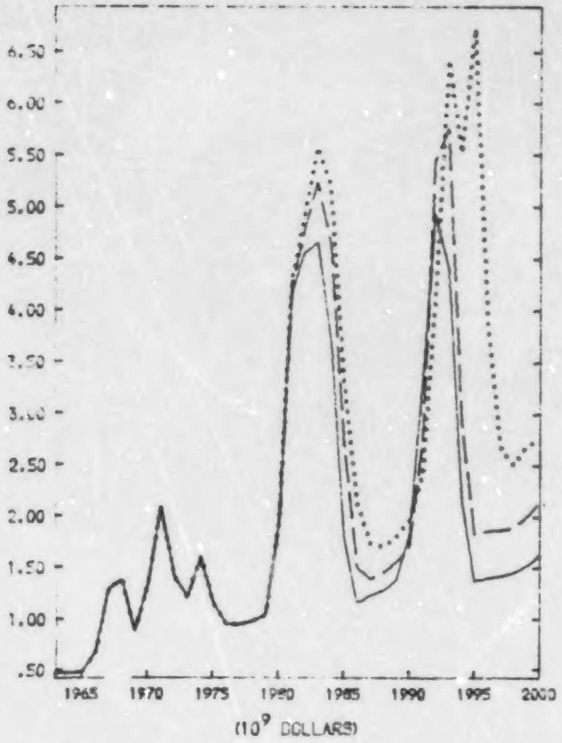


35-STONE AND CLAY PRODUCTS

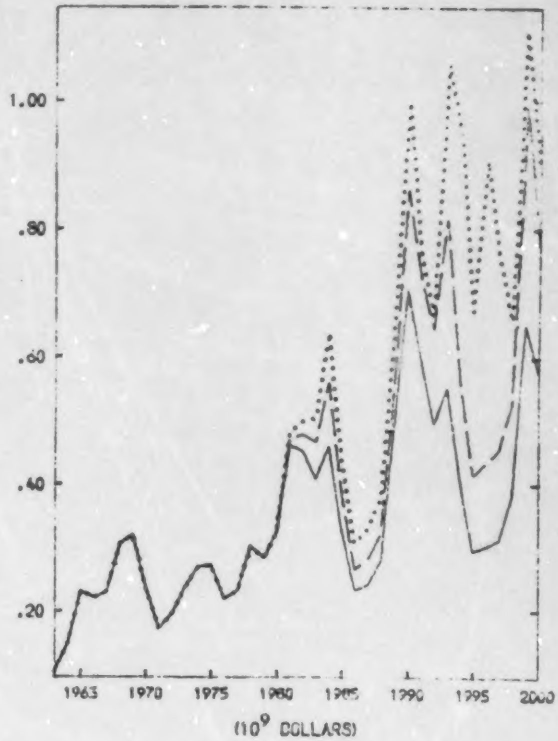


36-PRIMARY IRON AND STEEL MANUFACTURING

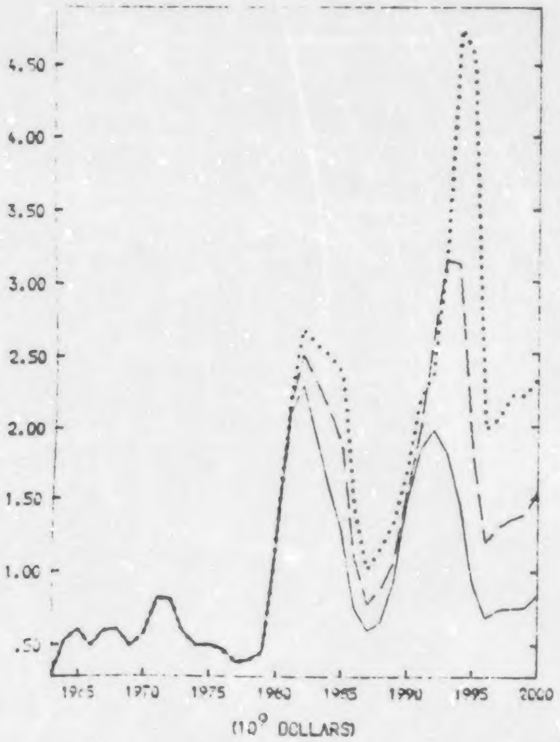
D. GROSS INVESTMENT BY SECTOR



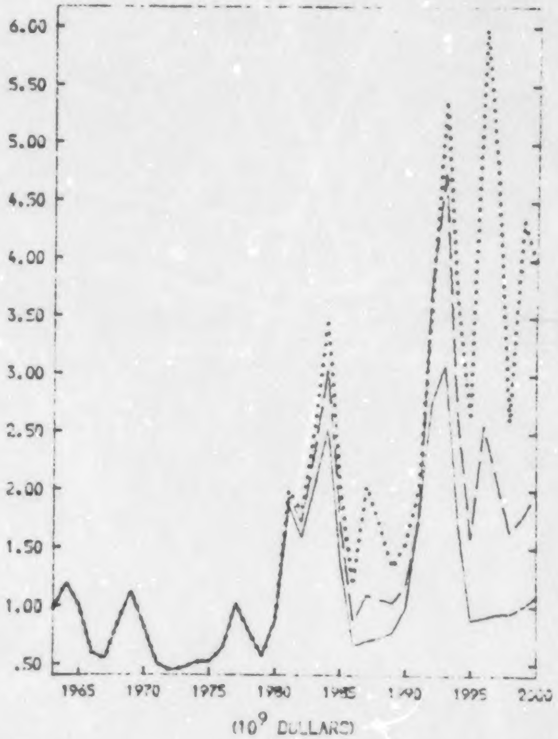
37-PRIMARY NONFERROUS METALS MANUFACTURE



38-METAL CONTAINERS

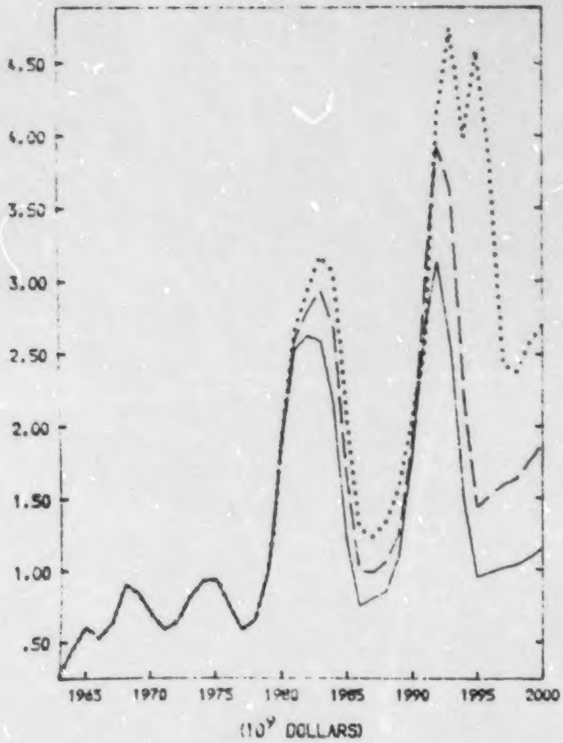


39-HEATING, PLUMBING, OTHER METAL PRODUCTS

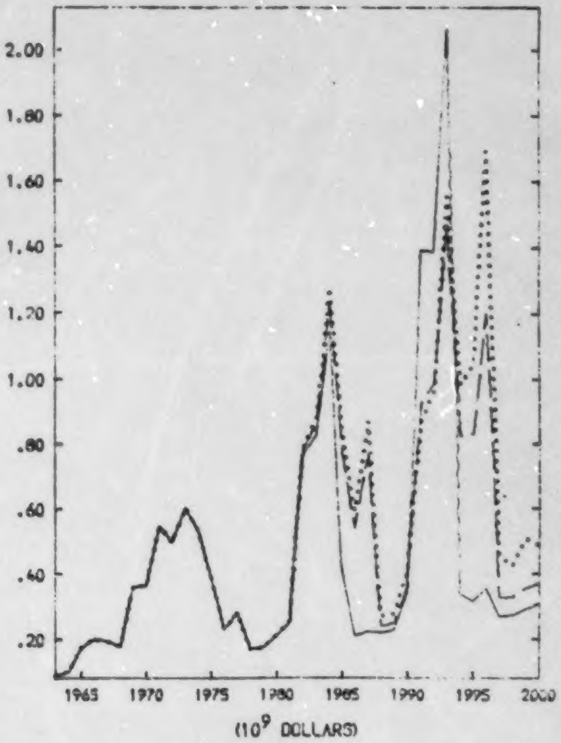


40-SCREW MACHINE PRODUCTS AND STAMPINGS

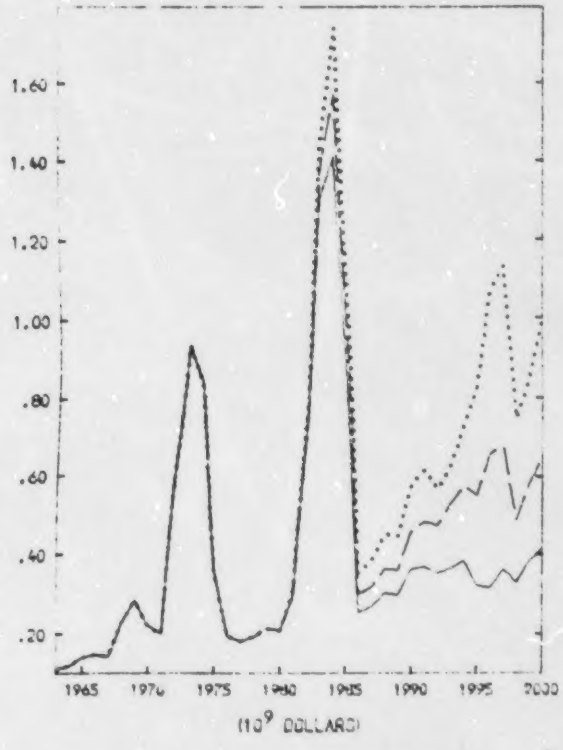
D. GROSS INVESTMENT BY SECTOR



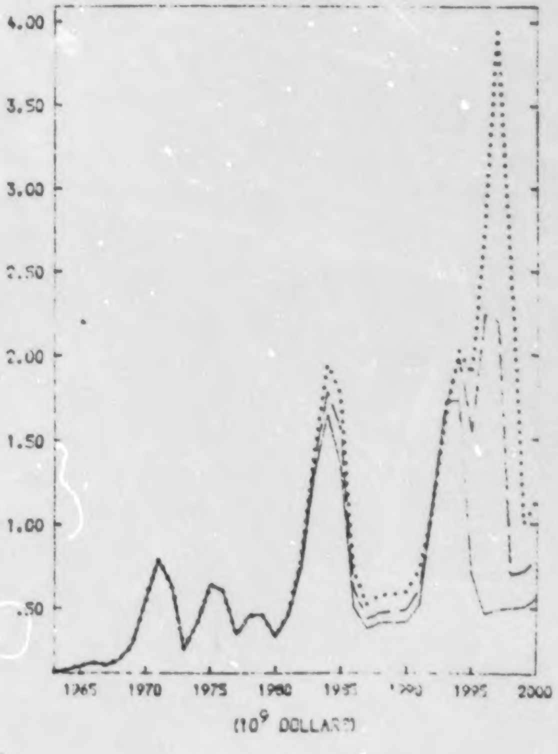
41-OTHER FABRICATED METAL PRODUCTS



42-ENGINES AND TURBINES

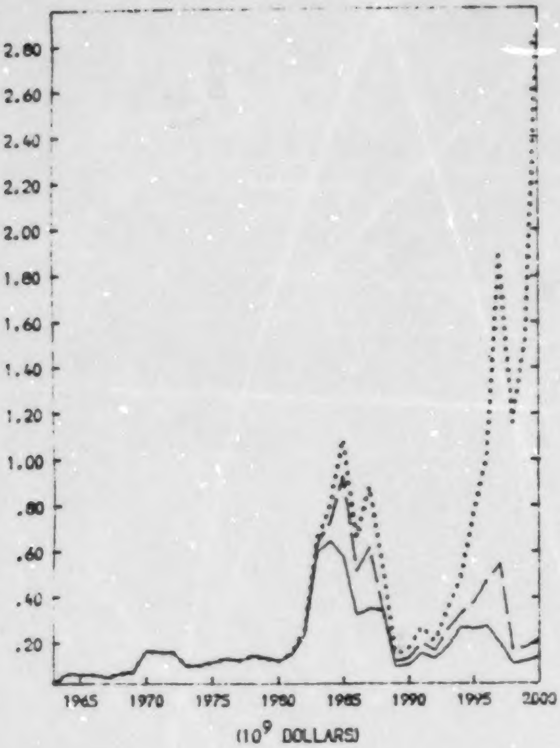


43-FARM AND GARDEN MACHINERY

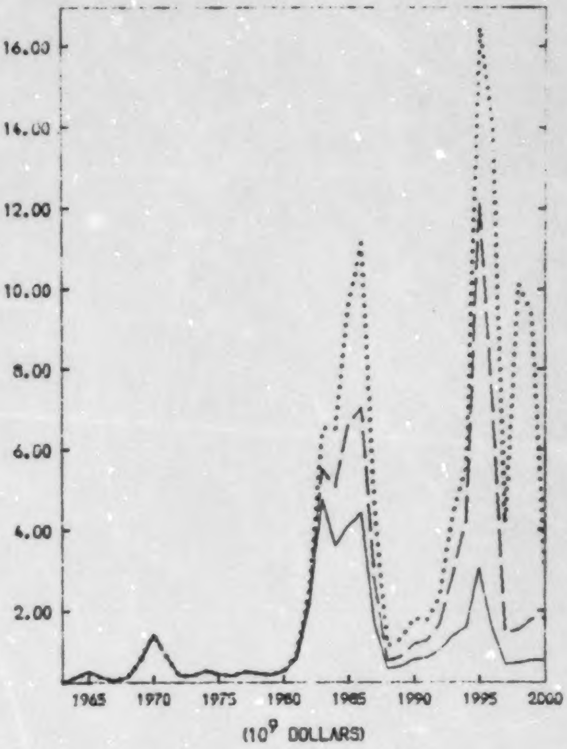


44-CONSTRUCTION AND MINING MACHINERY

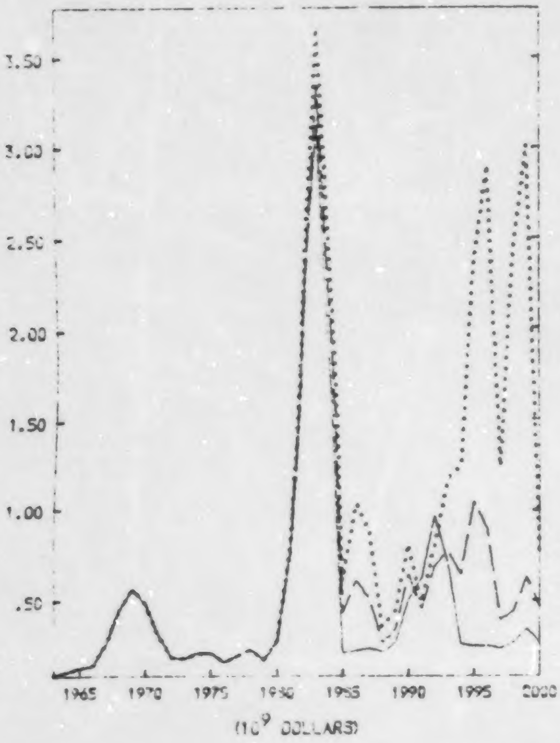
D. GROSS INVESTMENT BY SECTOR



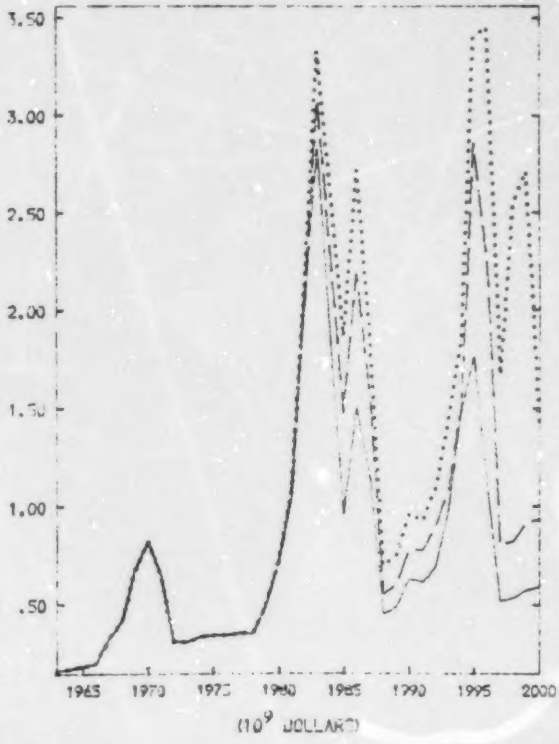
45-MATERIALS HANDLING EQUIPMENT



46-METALWORKING MACHINERY AND EQUIPMENT

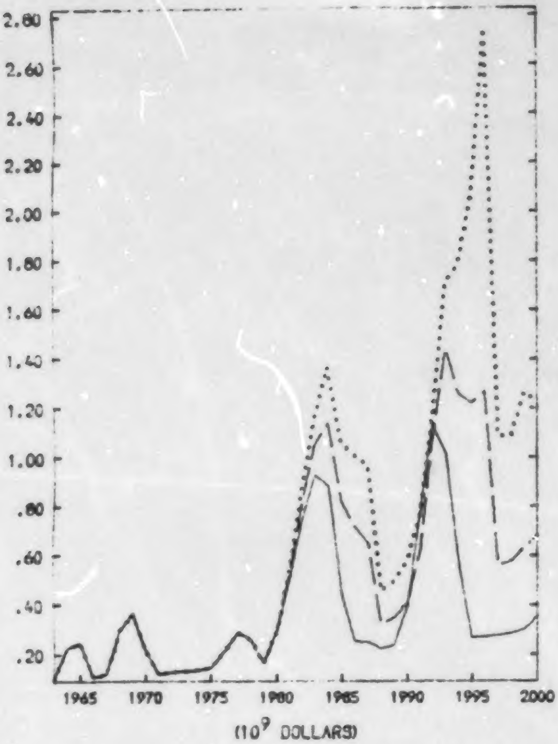


47-SPECIAL INDUSTRY EQUIPMENT

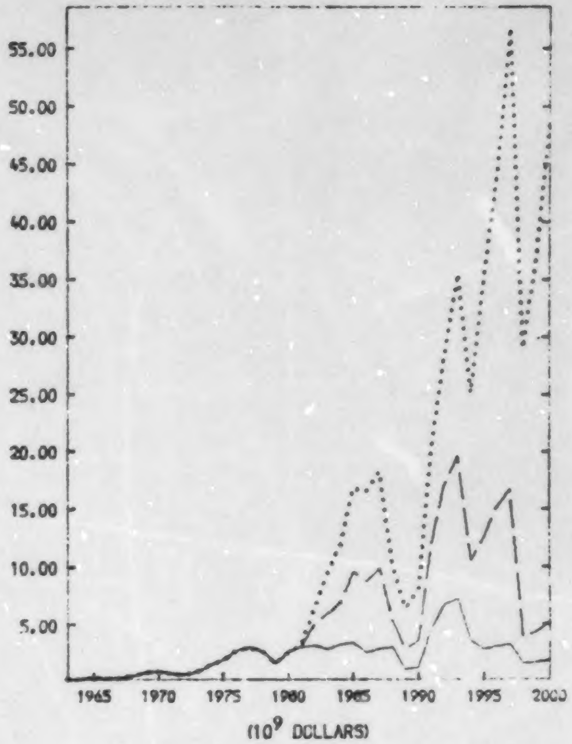


48-GENERAL INDUSTRIAL EQUIPMENT

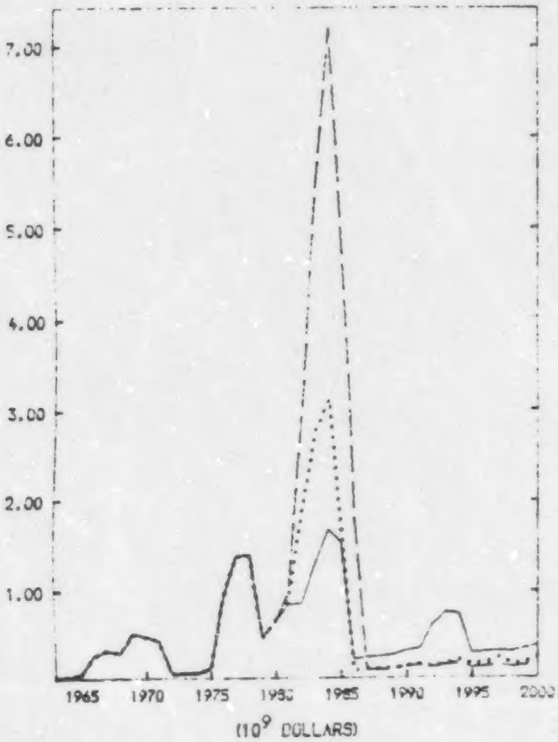
D. GROSS INVESTMENT BY SECTOR



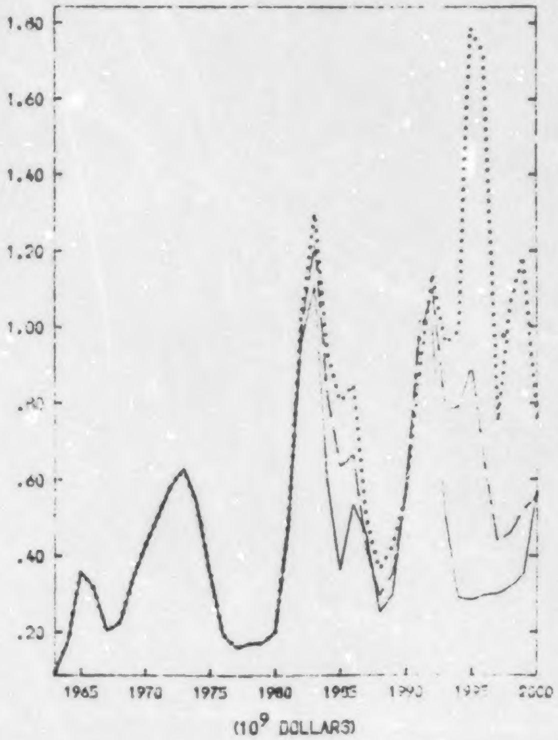
49-MISC MACHINERY, EXCEPT ELECTRICAL



50-ELECTRONIC COMPUTING EQUIPMENT

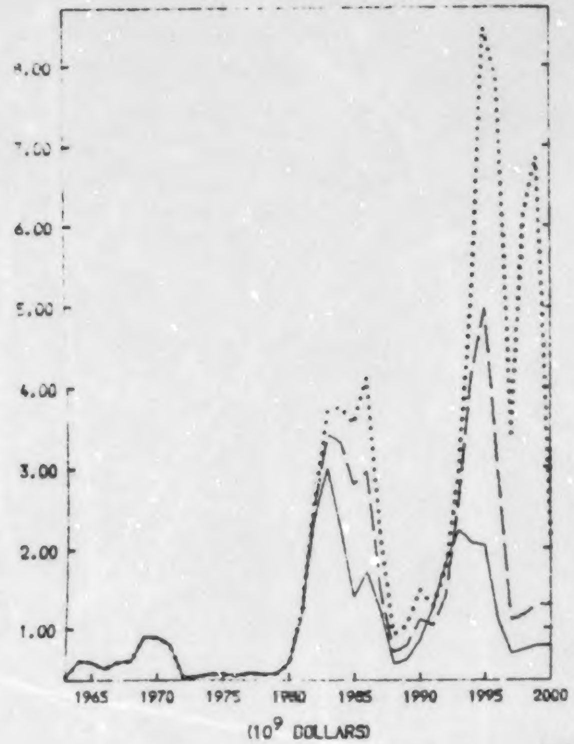


51-OFFICE MACHINES, EXCEPT COMPUTERS

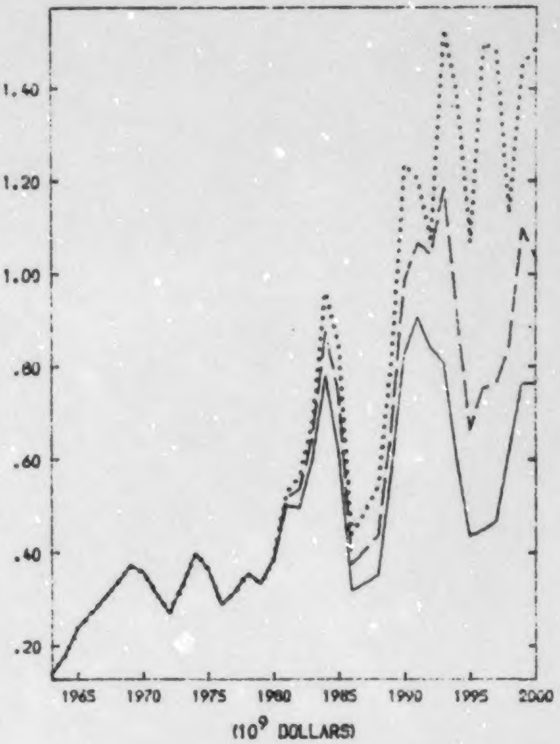


52-SERVICE INDUSTRY MACHINES

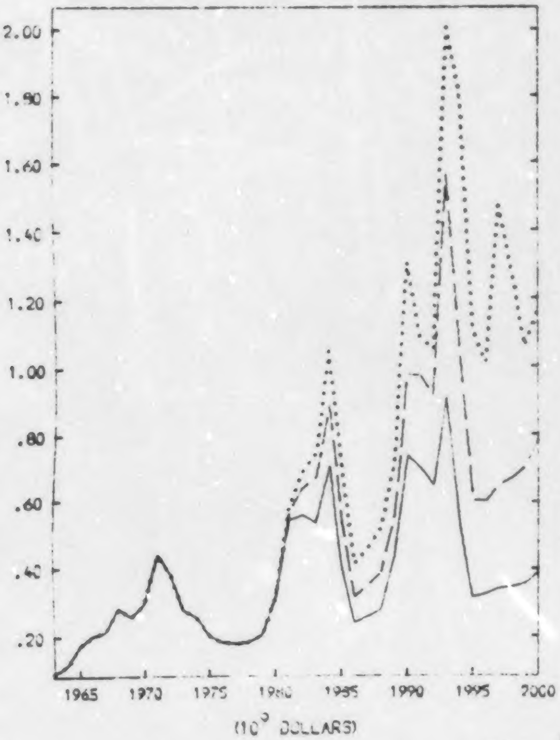
D. GROSS INVESTMENT BY SECTOR



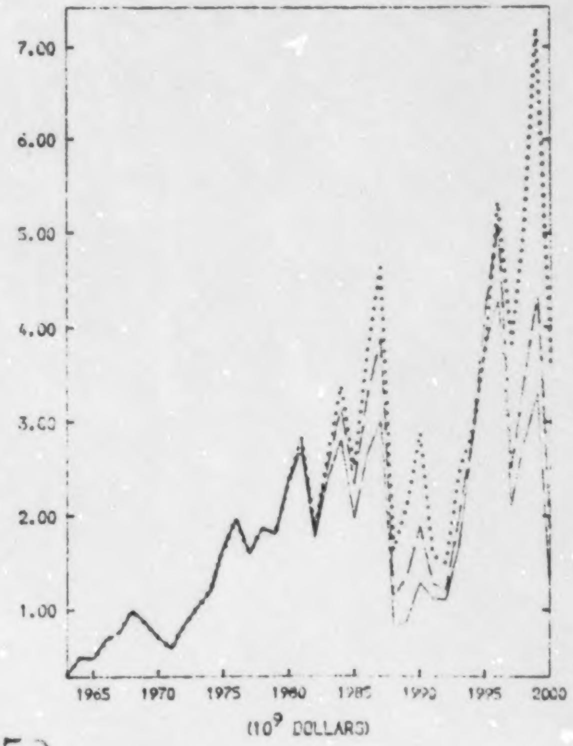
53-ELECTRIC INDUSTRIAL EQUIPMENT



54-HOUSEHOLD APPLIANCES

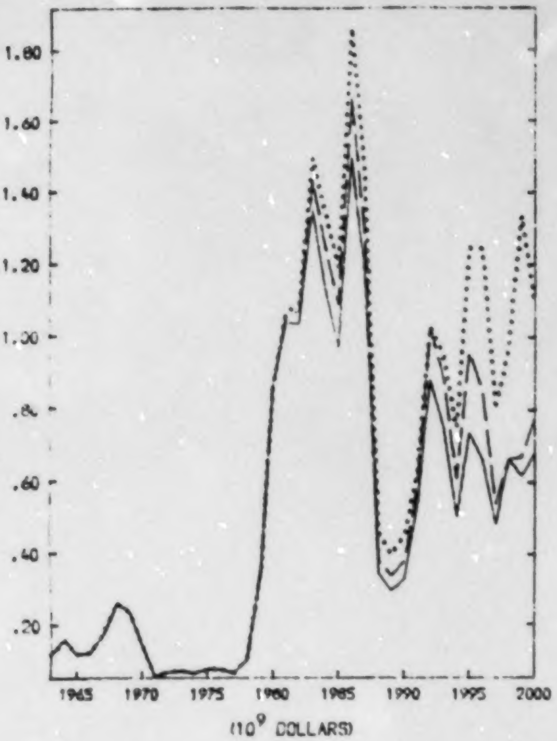


55-ELECTRIC LIGHTING AND WIRING EQUIP.

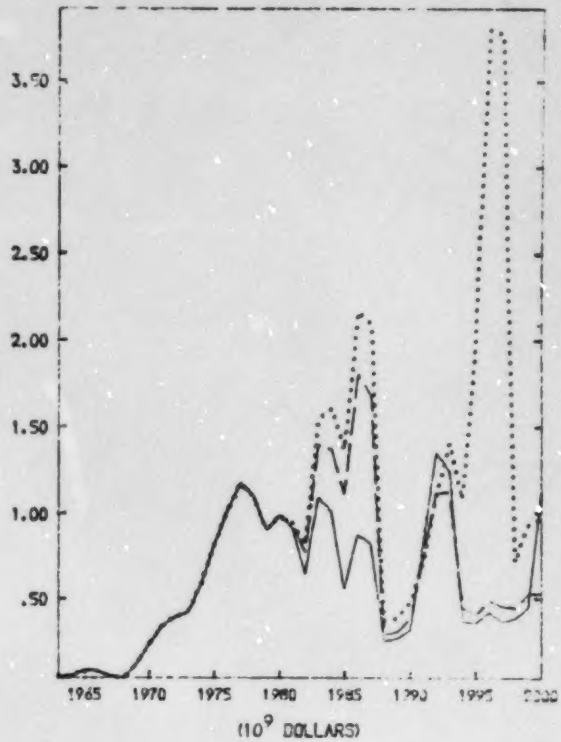


56-RADIO, TV AND COMMUNICATIONS EQUIPMENT

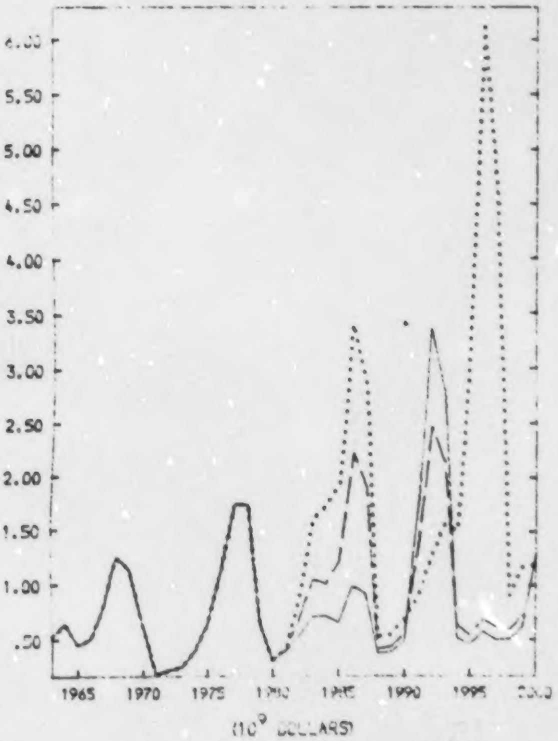
D. GROSS INVESTMENT BY SECTOR



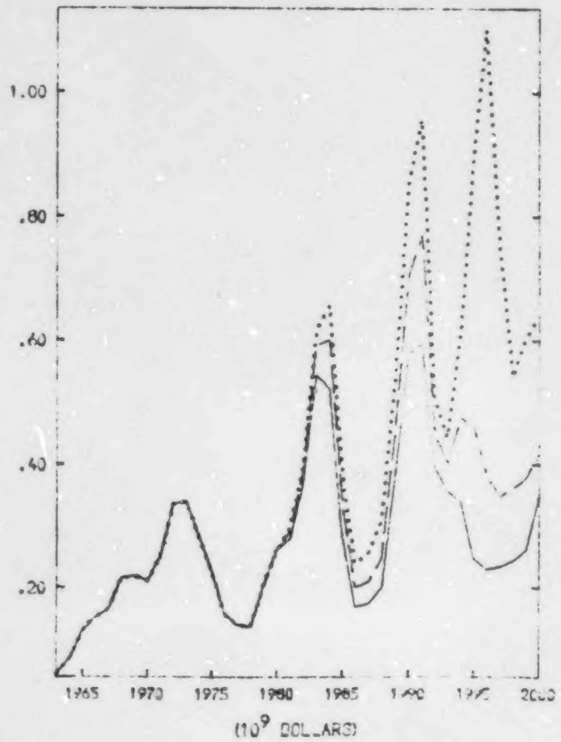
57-ELECTRON TUBES



58-SEMICONDUCTORS AND RELATED DEVICES

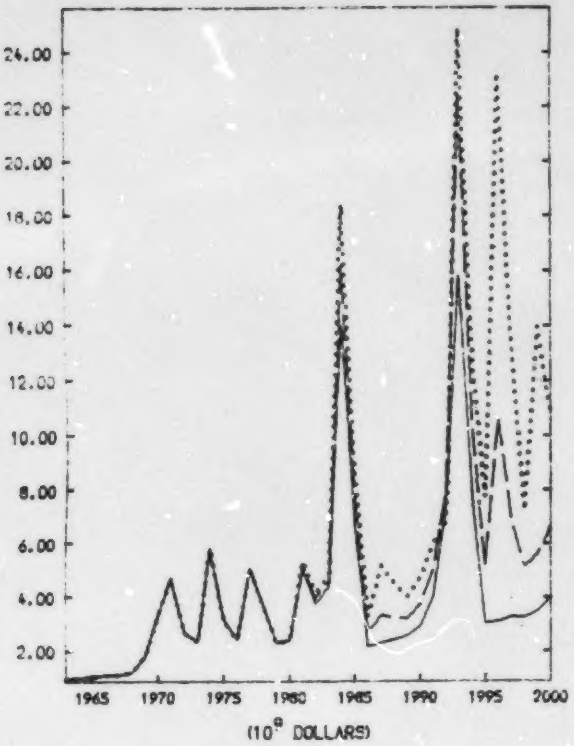


59-ELECTRONIC COMPONENTS, NEC

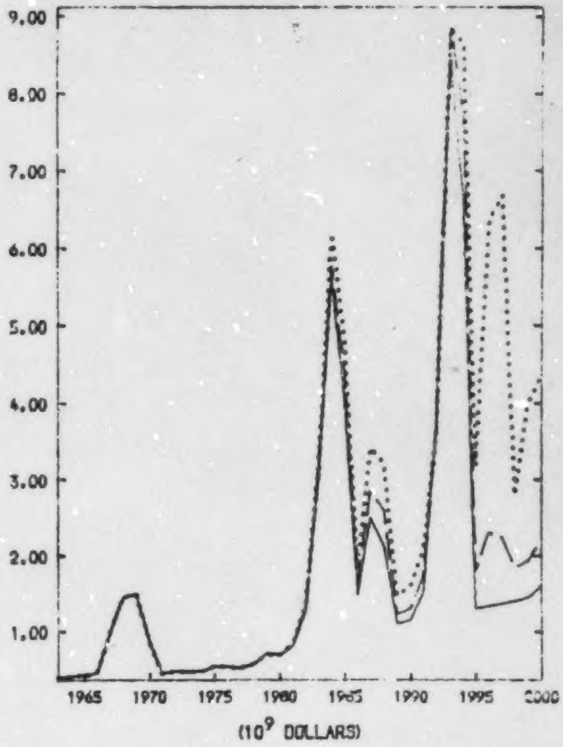


60-MISC ELECTRIC. MACHINERY AND SUPPLIES

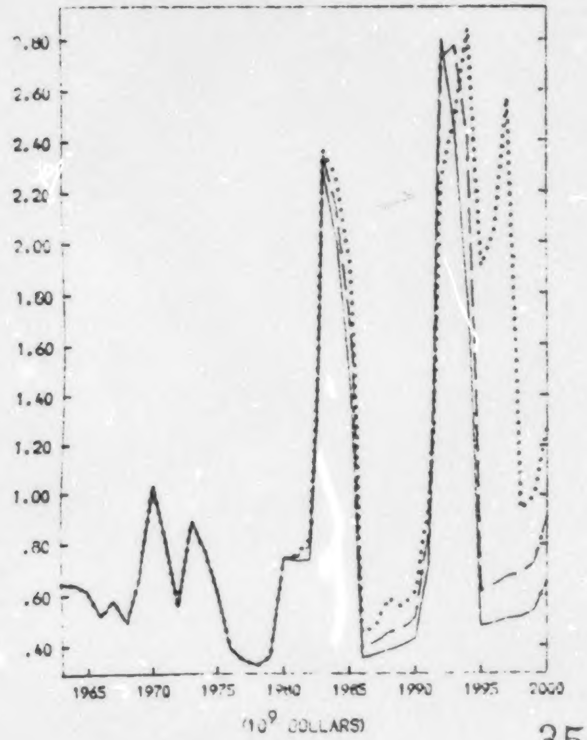
D. GROSS INVESTMENT BY SECTOR



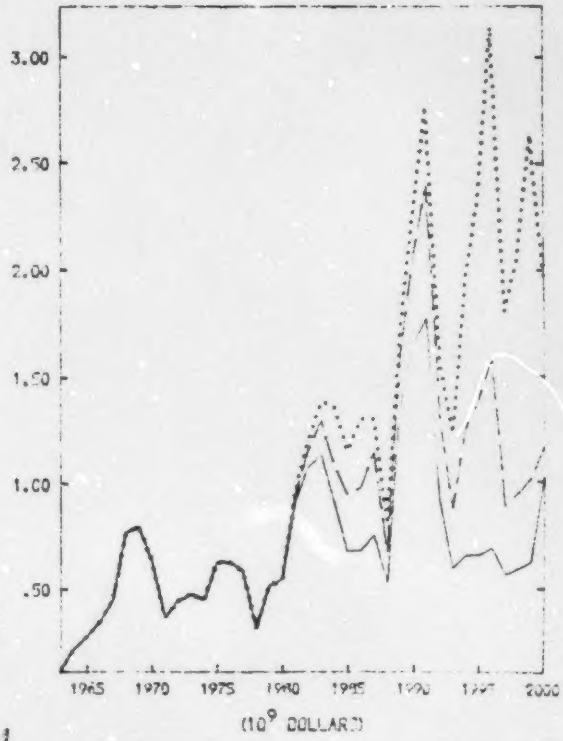
61-MOTOR VEHICLES AND EQUIPMENT



62-AIRCRAFT AND PARTS

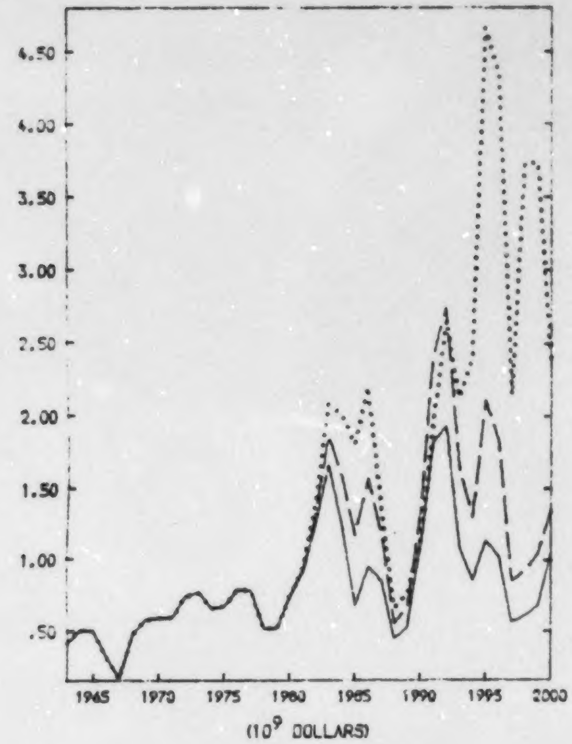


63-OTHER TRANSPORTATION EQUIPMENT

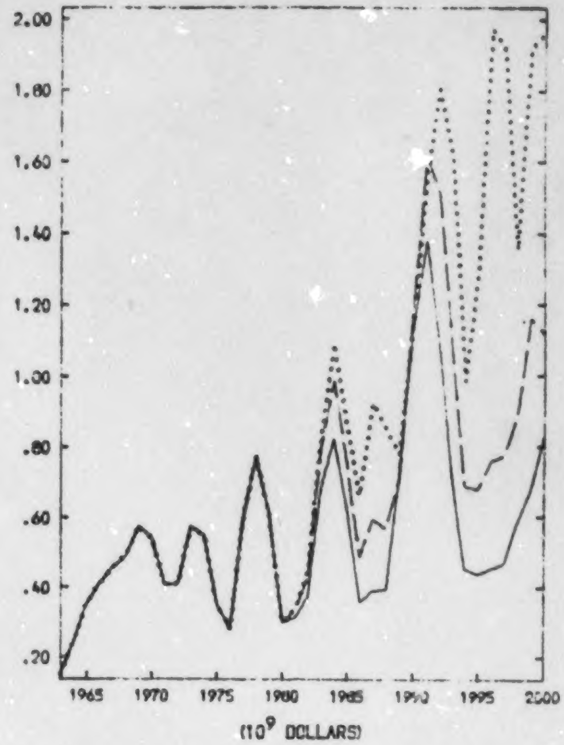


64-SCIENTIFIC AND CONTROL INSTRUMENTS

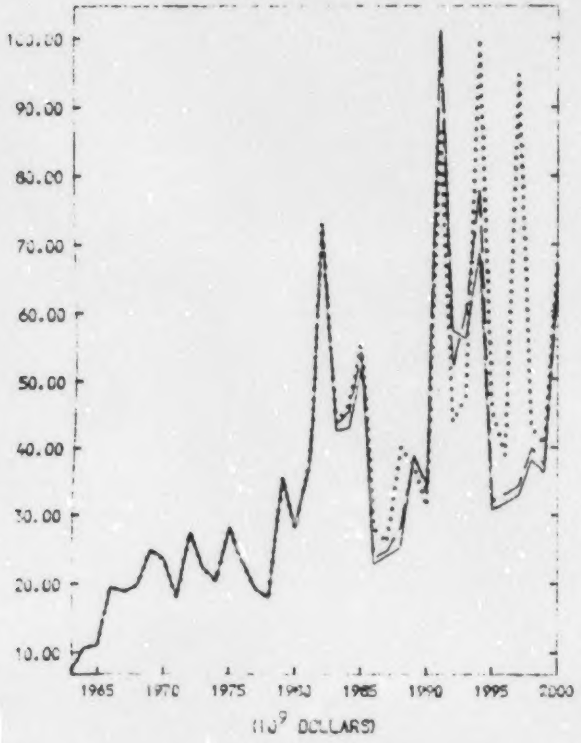
D. GROSS INVESTMENT BY SECTOR



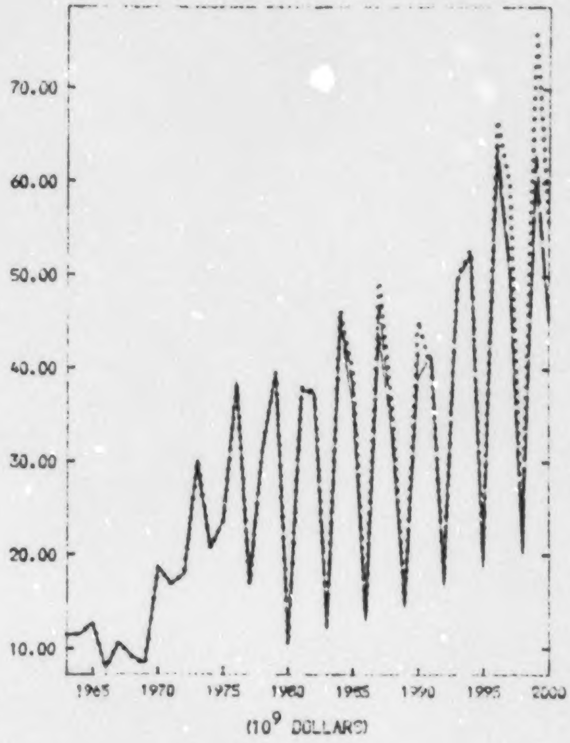
65-OPTICAL AND PHOTOGRAPHIC EQUIPMENT



66-MISCELLANEOUS MANUFACTURING

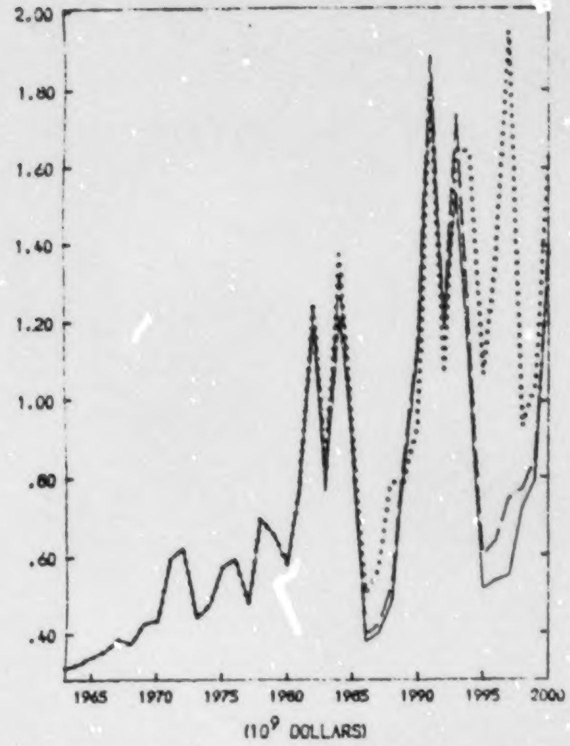


67-TRANSPORTATION AND WAREHOUSING

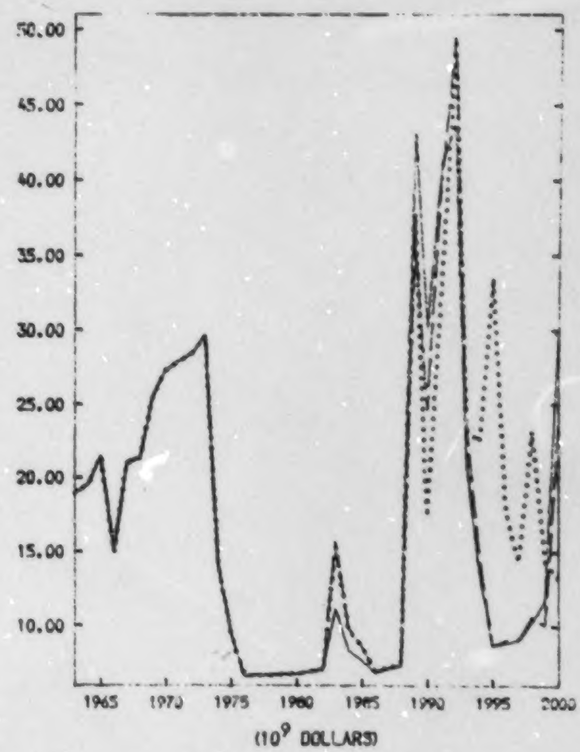


68-COMMUNICATIONS, EXCEPT RADIO AND TV

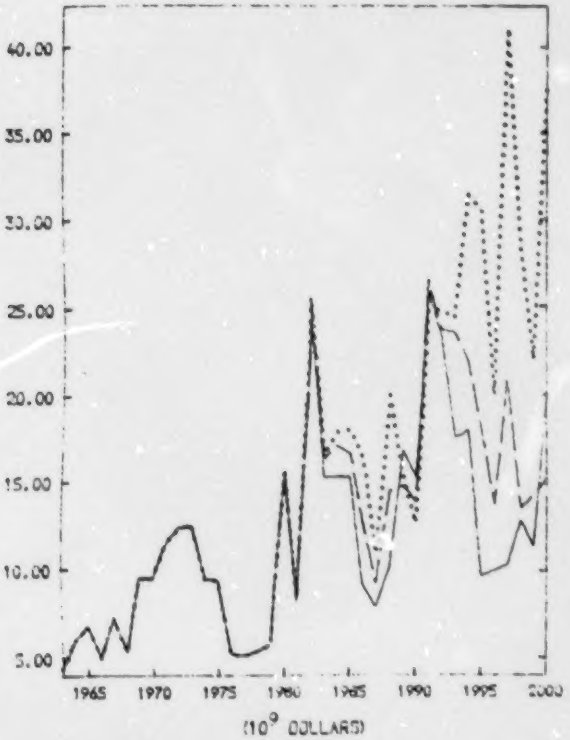
D. GROSS INVESTMENT BY SECTOR



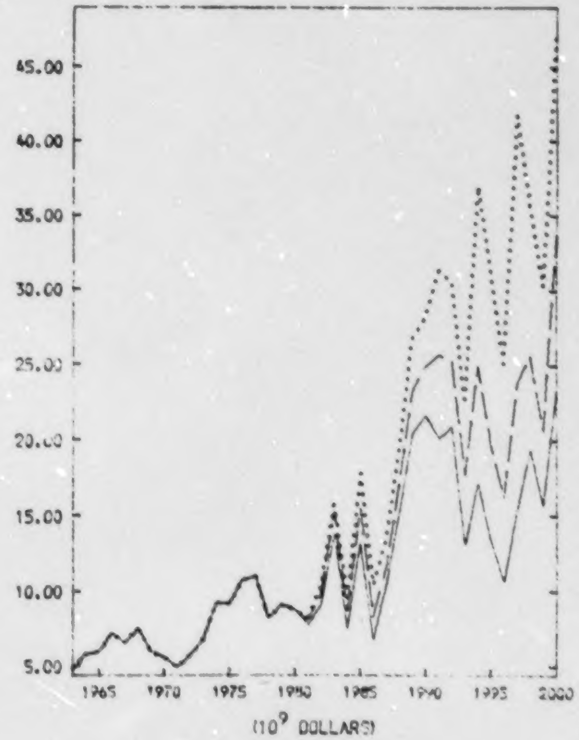
69-RADIO AND TV BROADCASTING



70-ELECTRIC, GAS AND WATER SERVICES

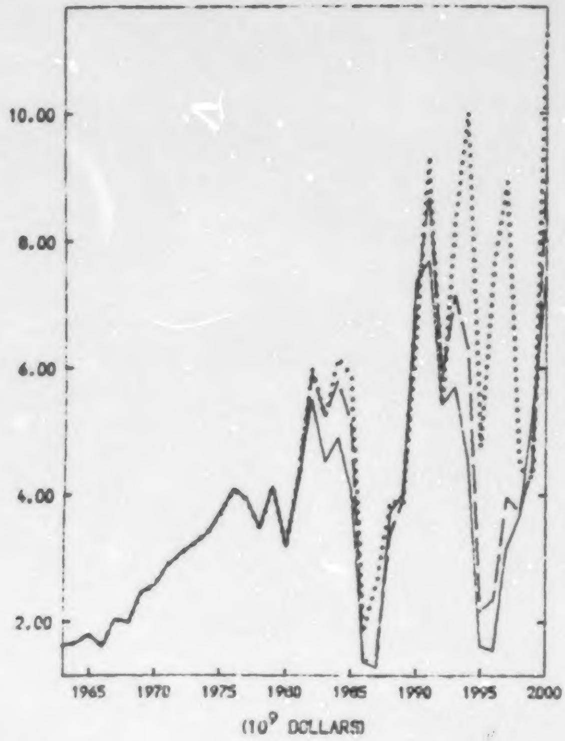


71-WHOLESALE TRADE

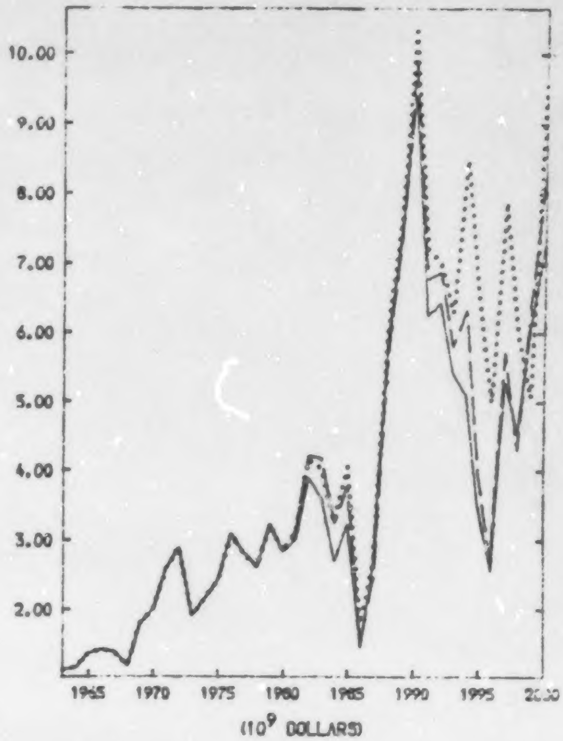


72-RETAIL TRADE

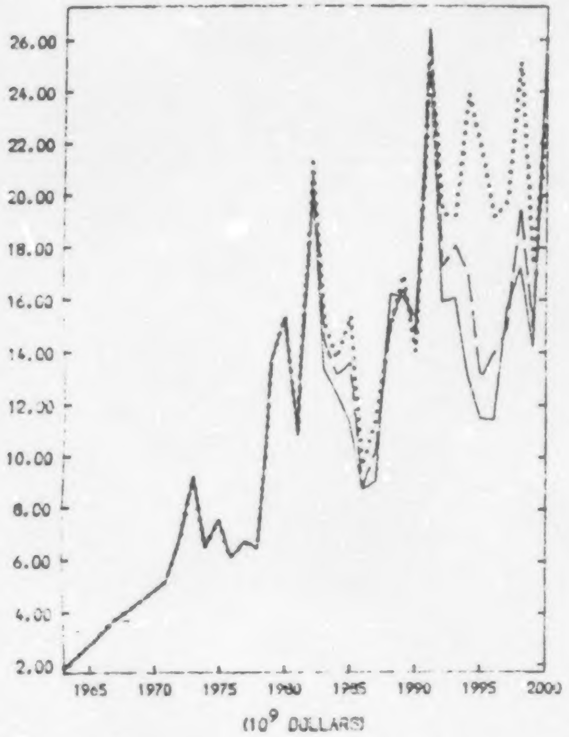
D. GROSS INVESTMENT BY SECTOR



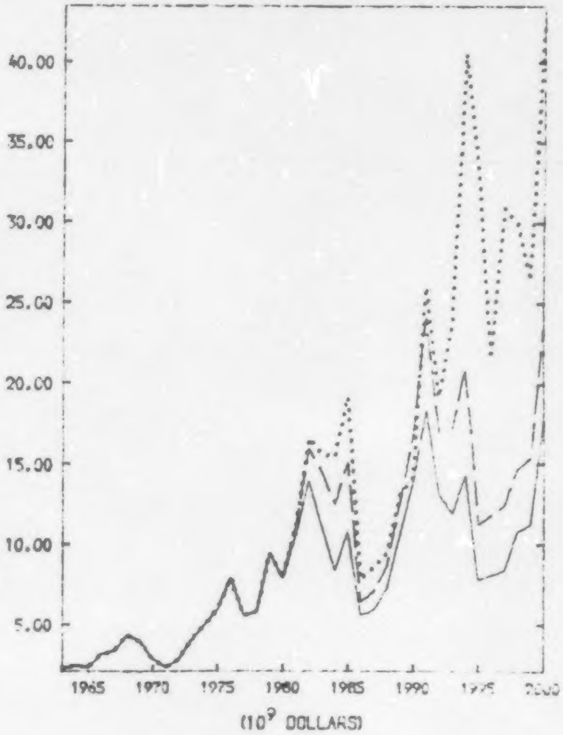
73-FINANCE



74-INSURANCE

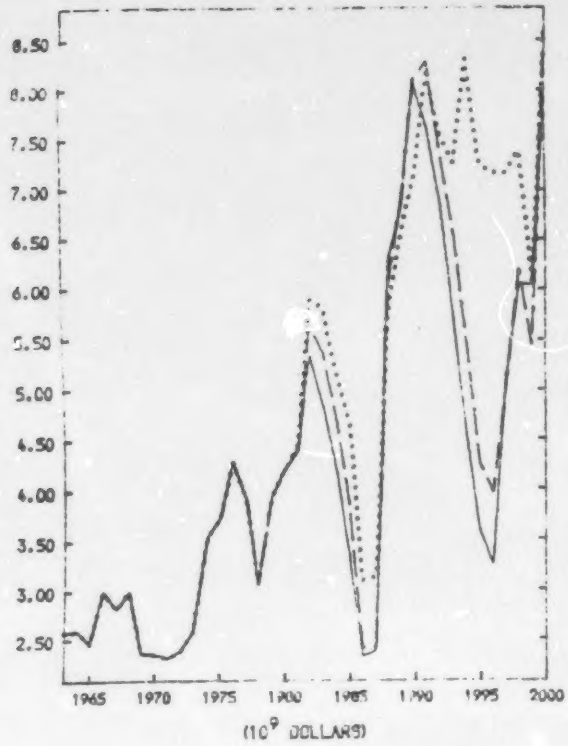


76-HOTELS, PERSONAL AND REPAIR SERVICES

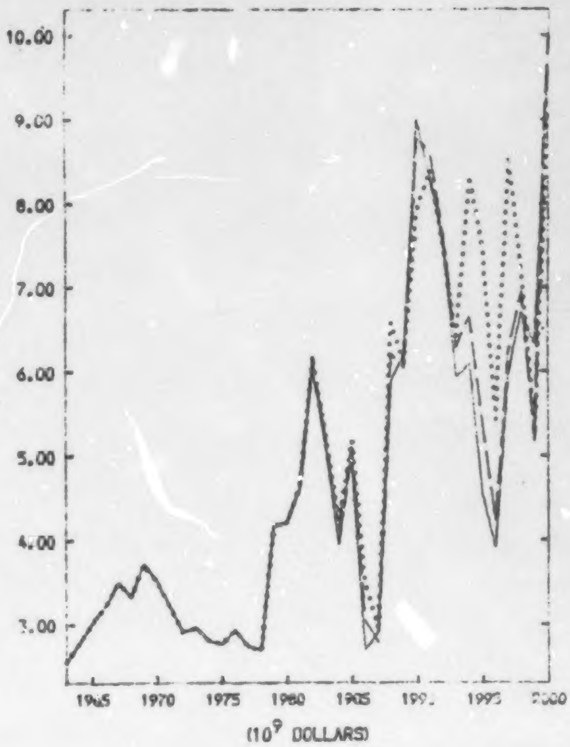


77-BUSINESS SERVICES

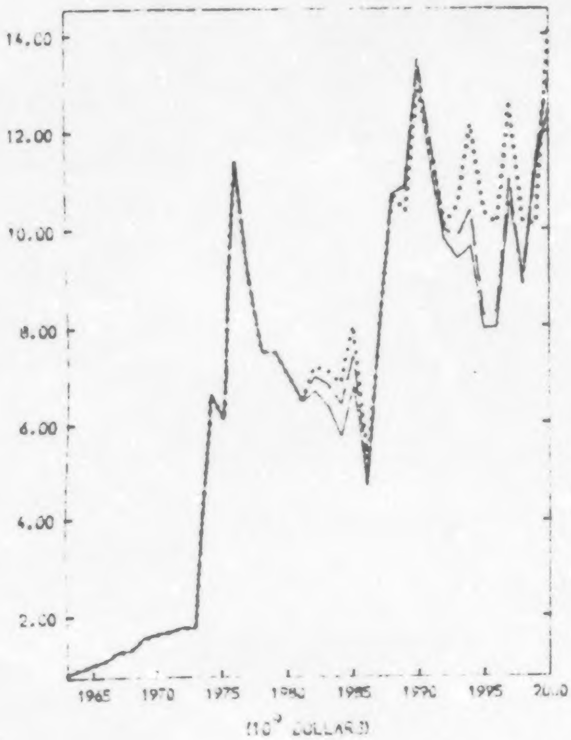
D. GROSS INVESTMENT BY SECTOR



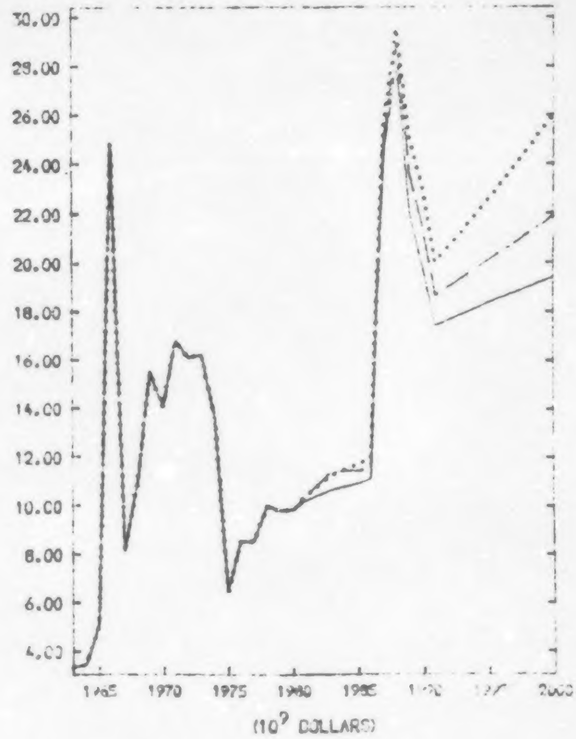
78-EATING AND DRINKING PLACES



79-AUTOMOBILE REPAIR SERVICES

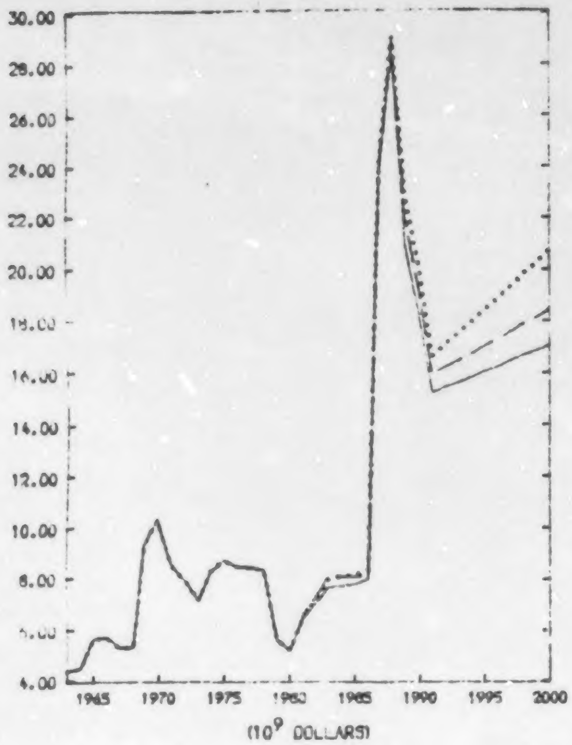


80-AMUSEMENTS

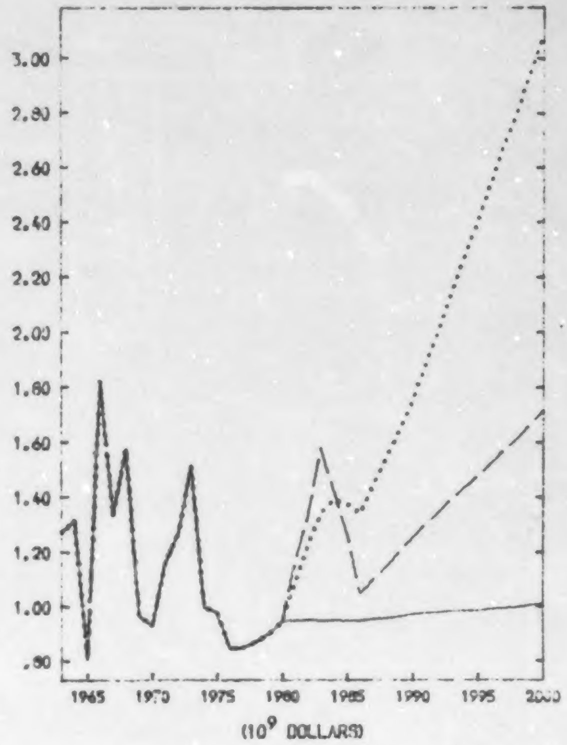


81-HOSPITALS

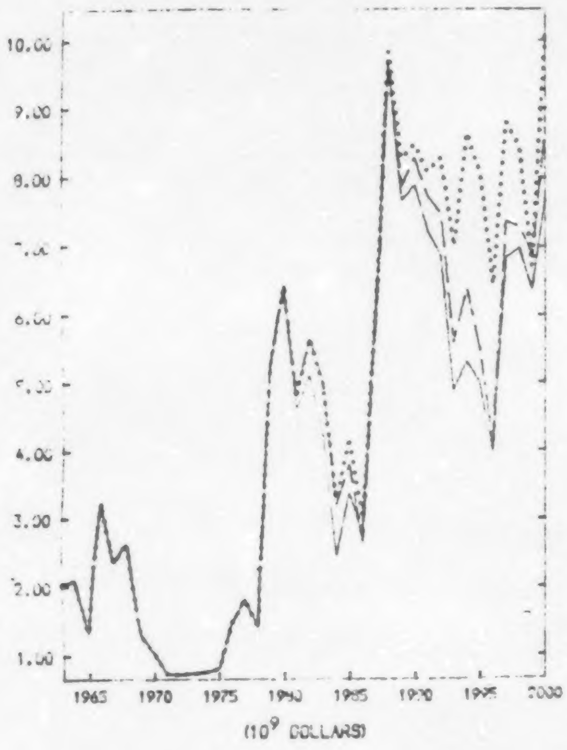
D. GROSS INVESTMENT BY SECTOR



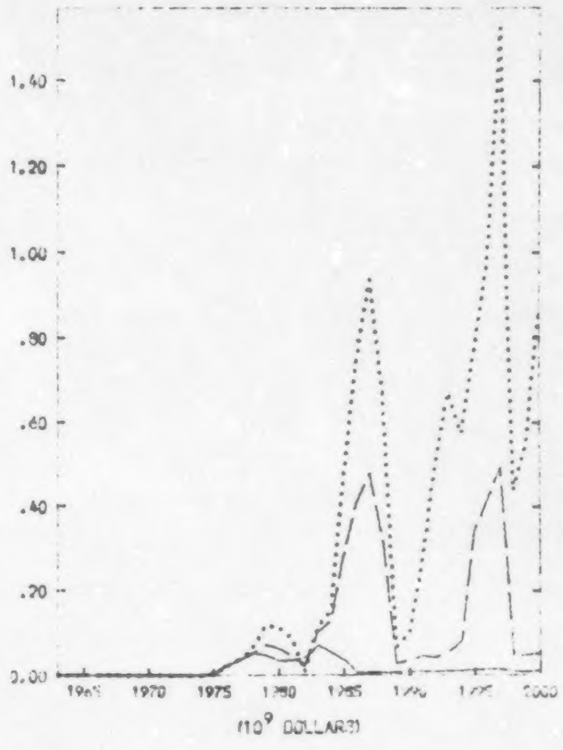
82-HEALTH SERVICES, EXCLUDING HOSPITALS



83-EDUCATIONAL SERVICES (PRIVATE)

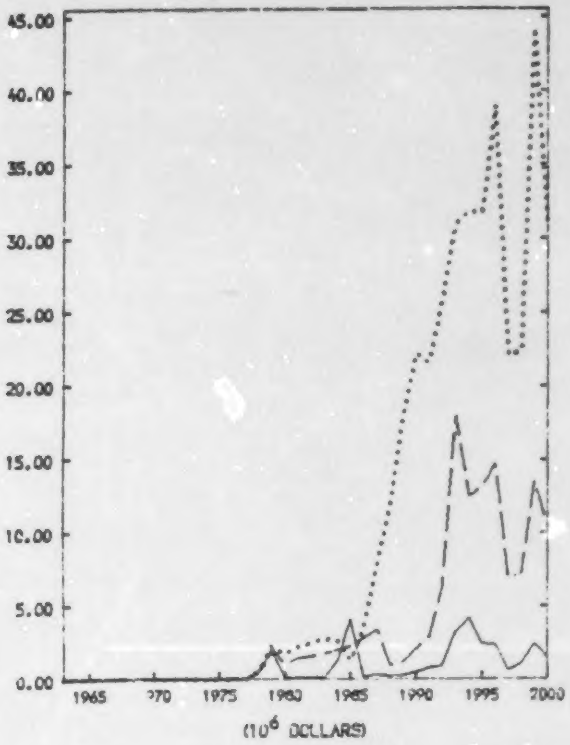


84-NONPROFIT ORGANIZATIONS

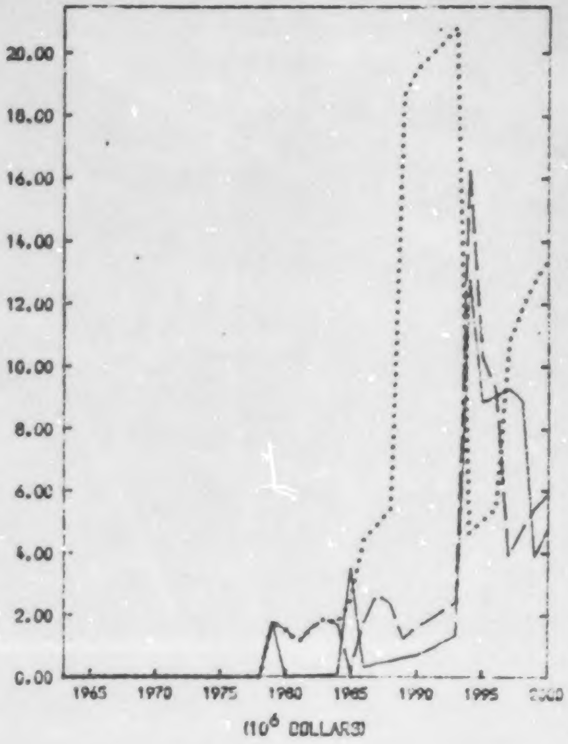


86-ROBOTICS MANUFACTURING

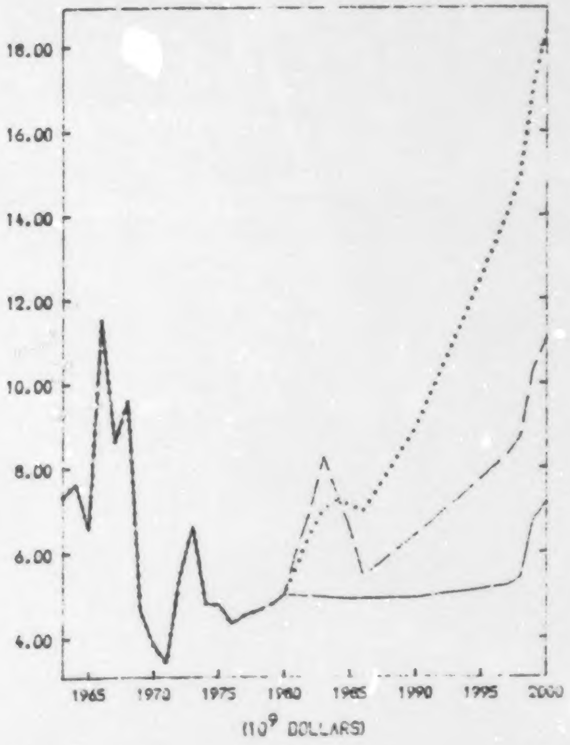
D. GROSS INVESTMENT BY SECTOR



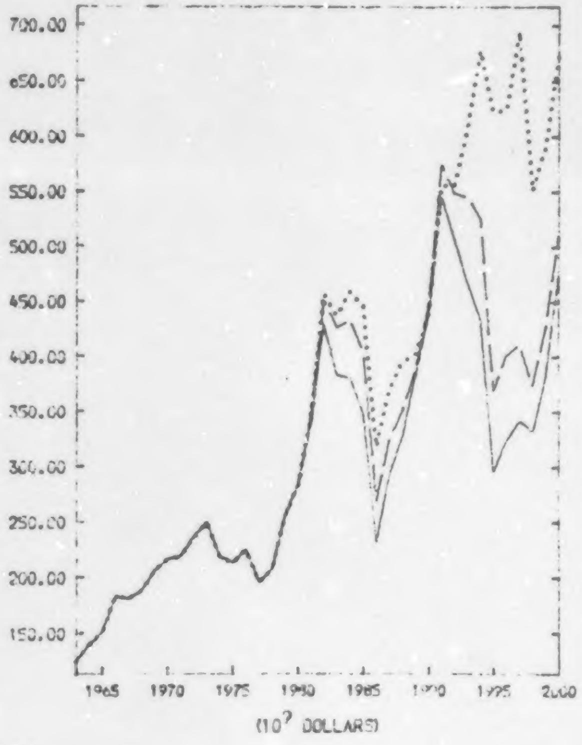
87-INSTRUCTIONAL TV



88-COMPUTER-BASED INSTRUCTION

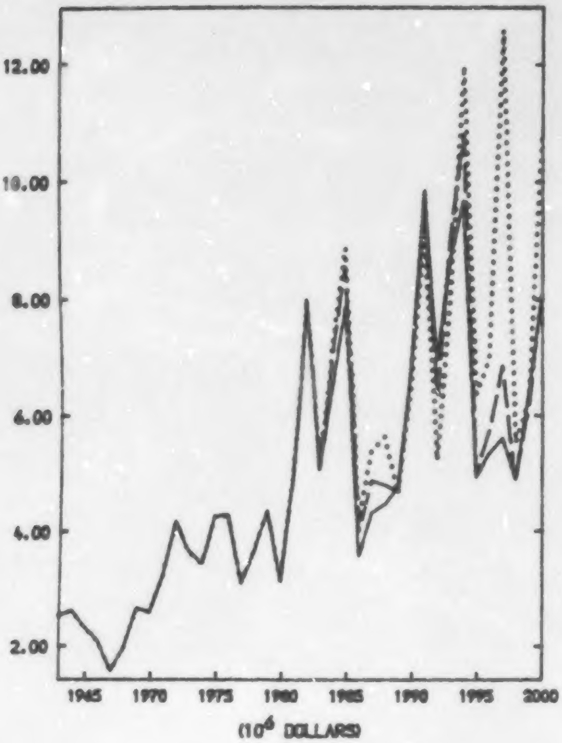


89-PUBLIC EDUCATION

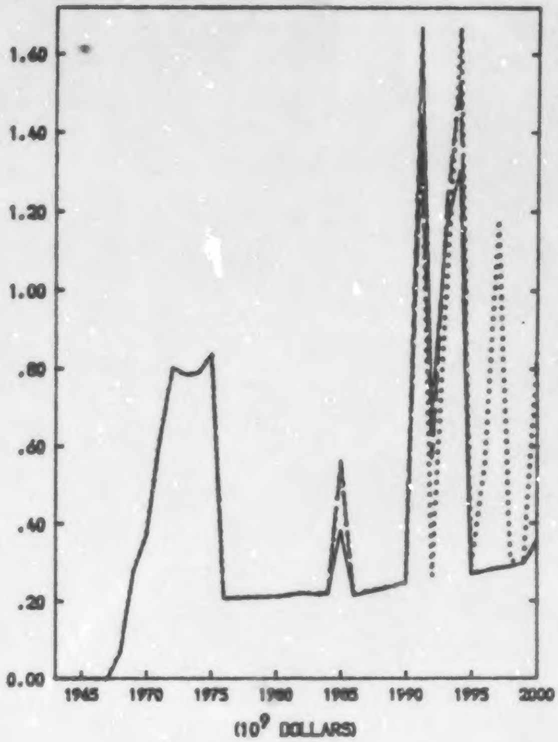


90-TOTAL

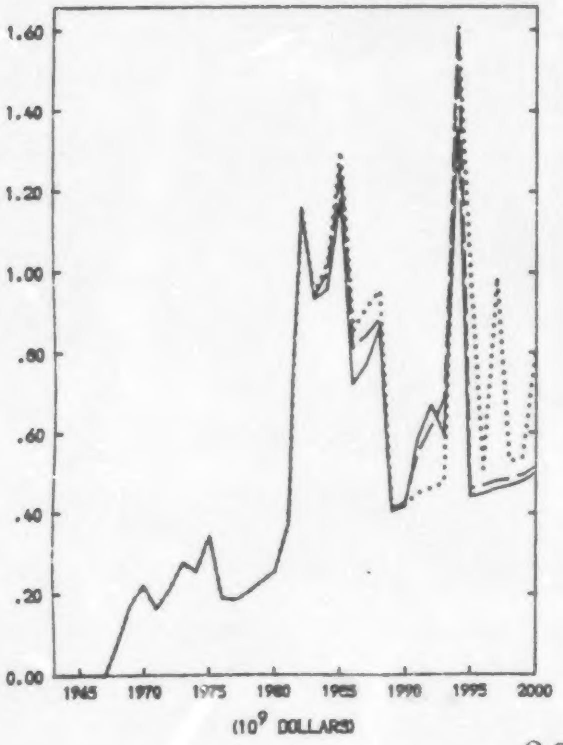
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



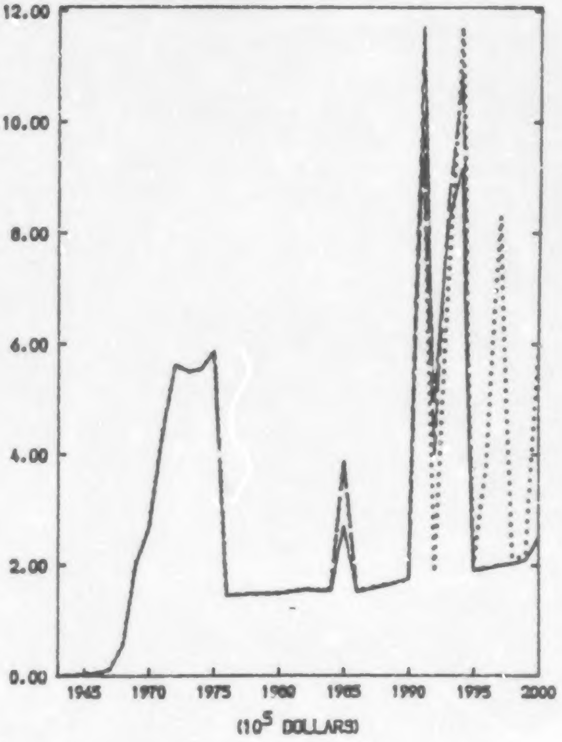
2-OTHER AGRICULTURAL PRODUCTS



6-NONFERROUS METAL ORES MINING

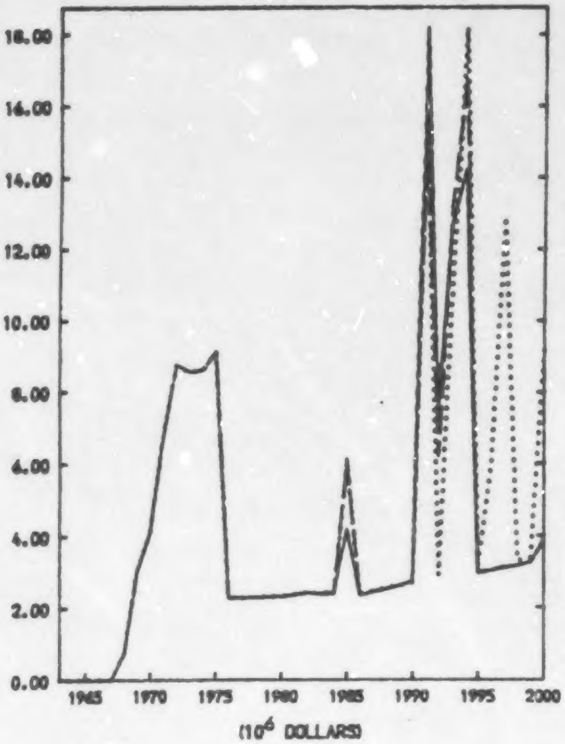


8-CRUDE PETROLEUM AND NATURAL GAS

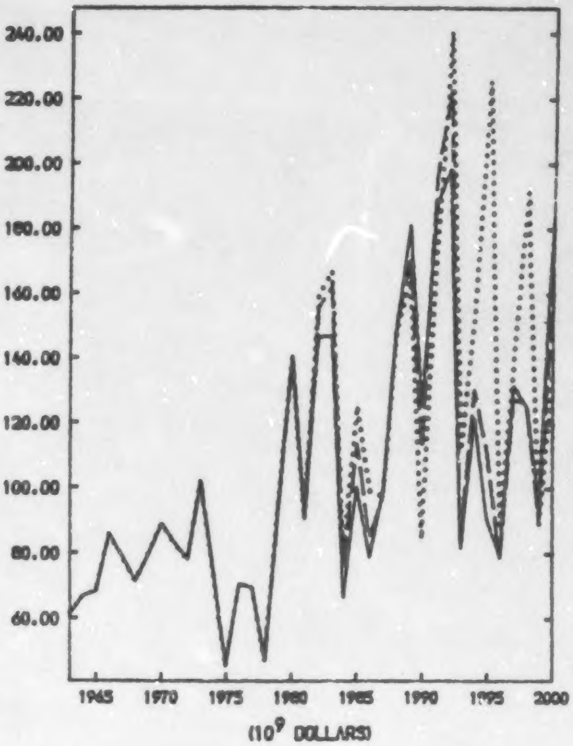


9-STONE AND CLAY MINING AND QUARRYING

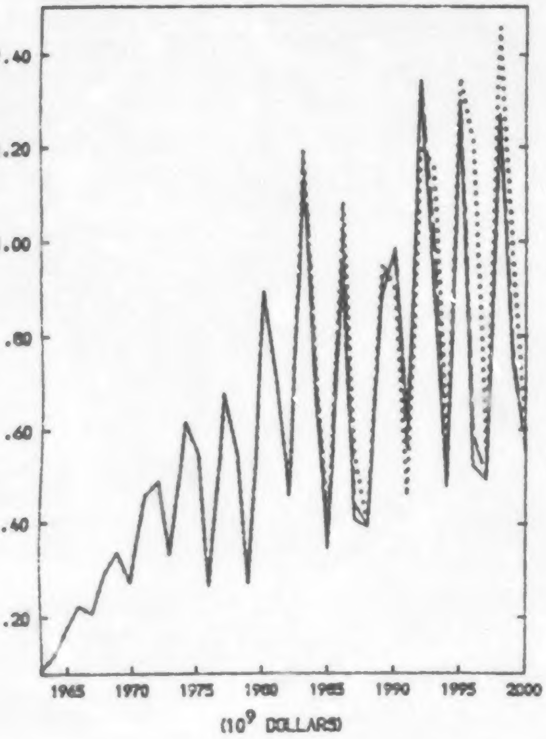
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



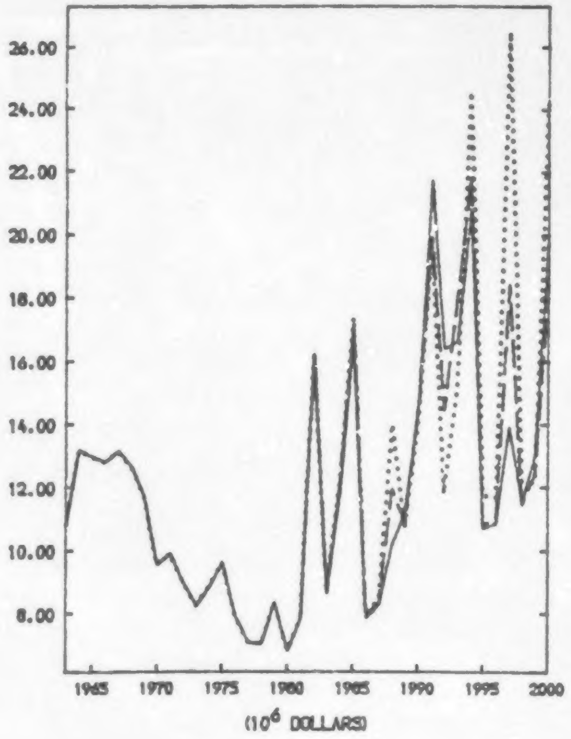
10-CHEM AND FERTILIZER MINERAL MINING



11-CONSTRUCTION

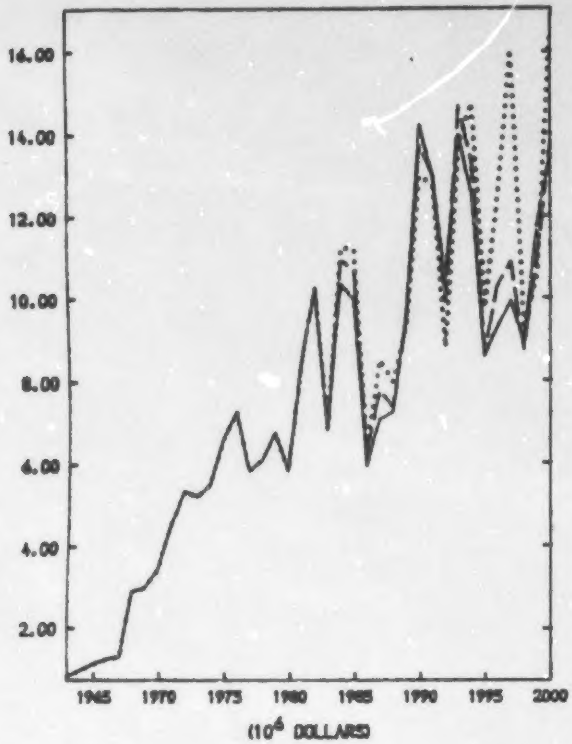


12-ORDNANCE AND ACCESSORIES

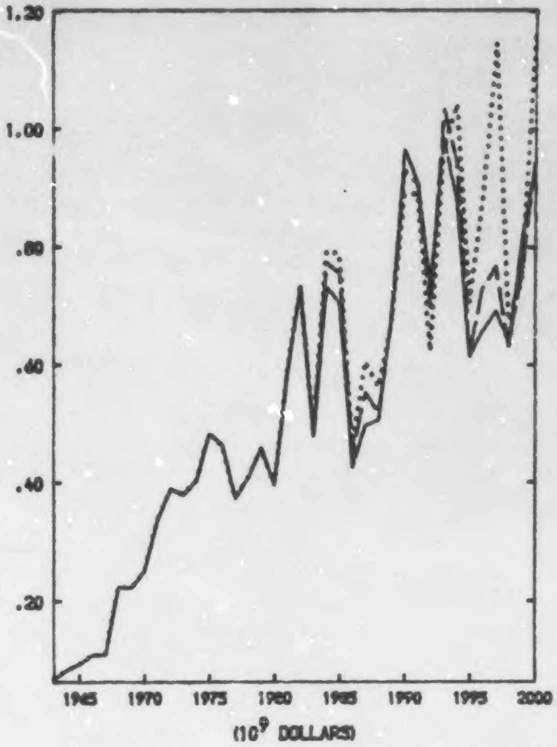


13-FOOD AND KINDRED PRODUCTS

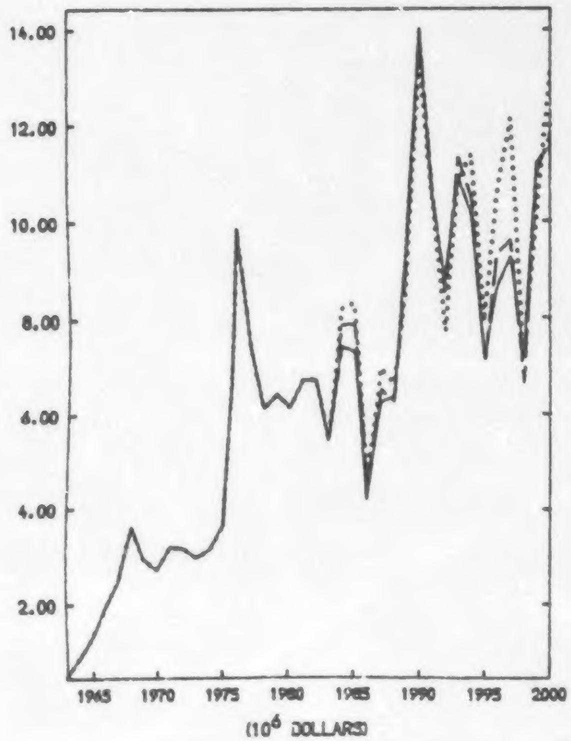
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



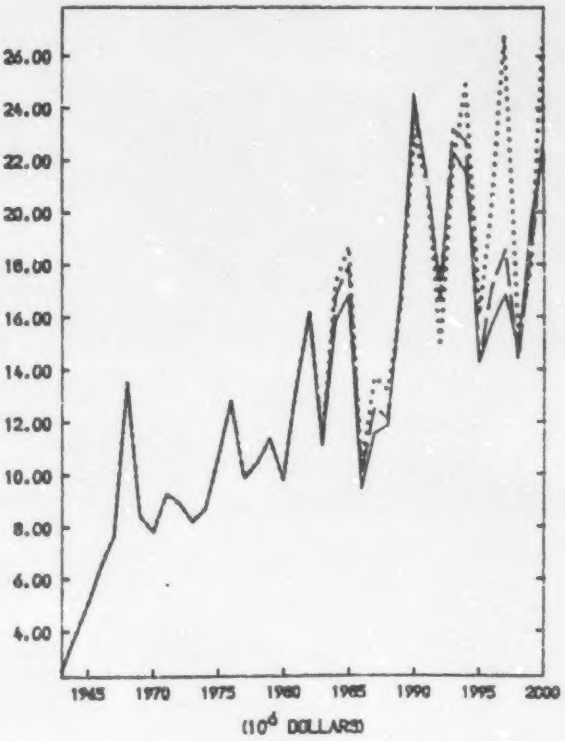
15-FABRICS, YARN AND THREAD MILLS



16-MISC TEXTILE GOODS AND FLOOR COVERING

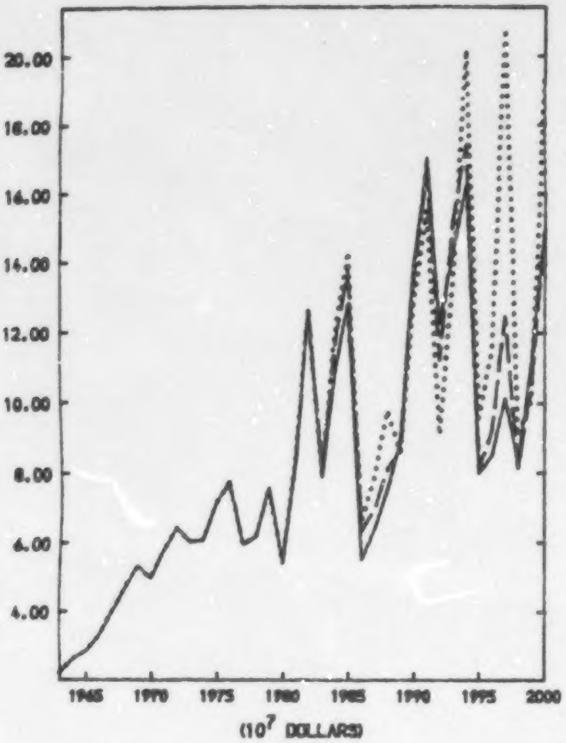


17-APPAREL

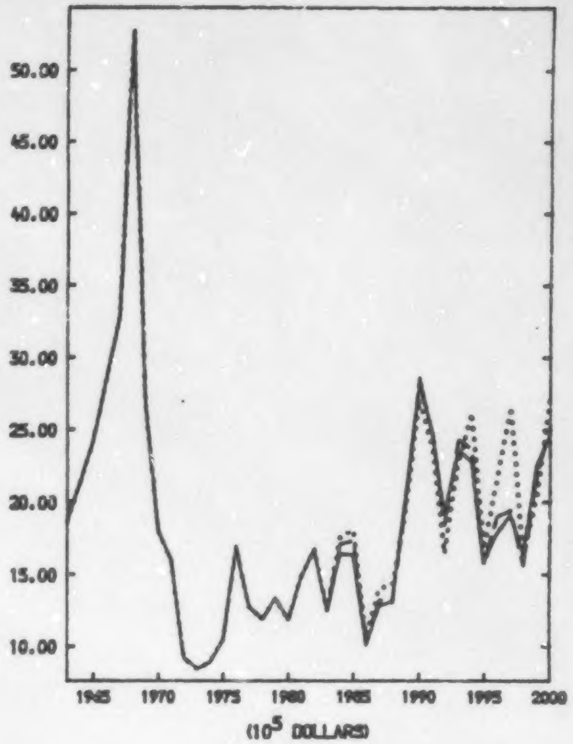


18-MISC FABRICATED TEXTILE PRODUCTS

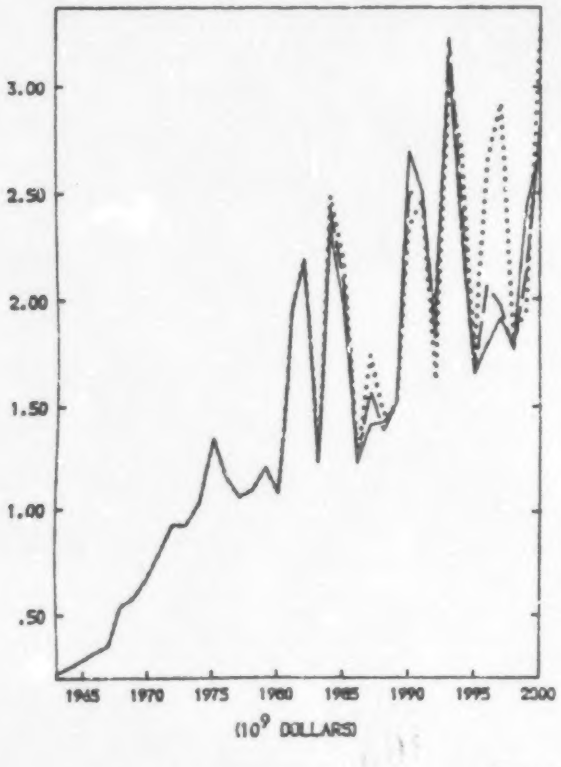
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



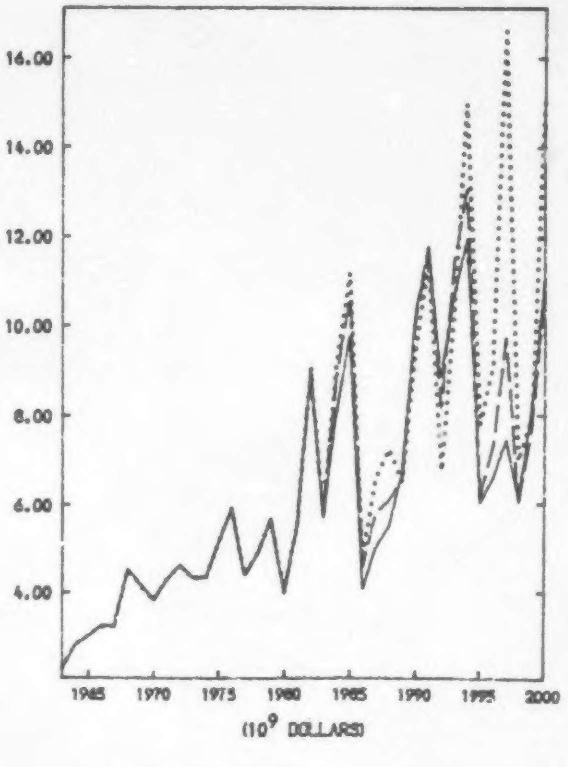
19-LUMBER AND WOOD PROD, EXC CONTAINERS



20-WOOD CONTAINERS

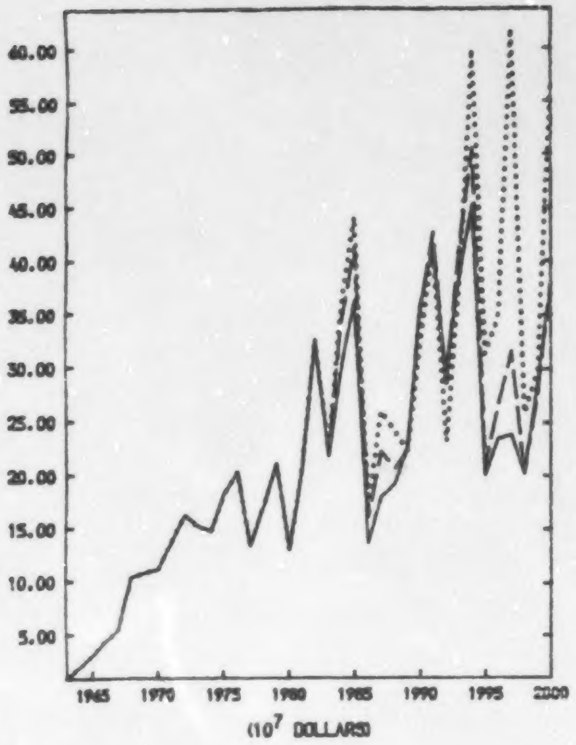


21-HOUSEHOLD FURNITURE

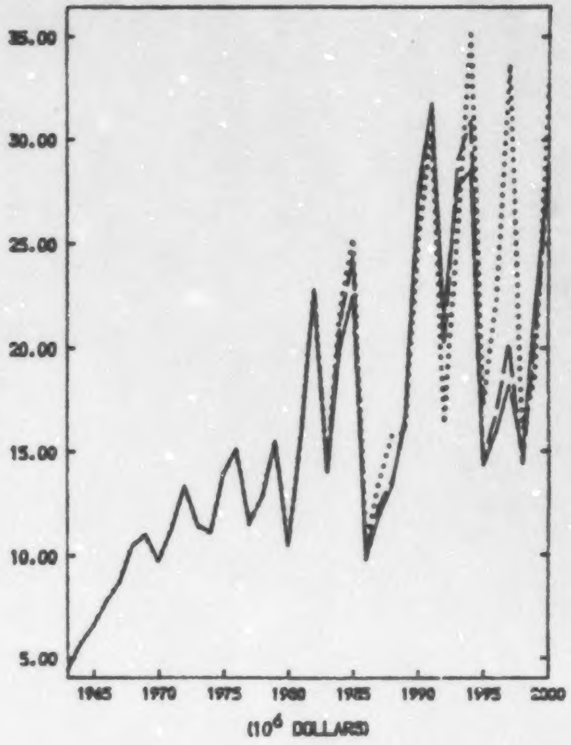


22-OTHER FURNITURE AND FIXTURES

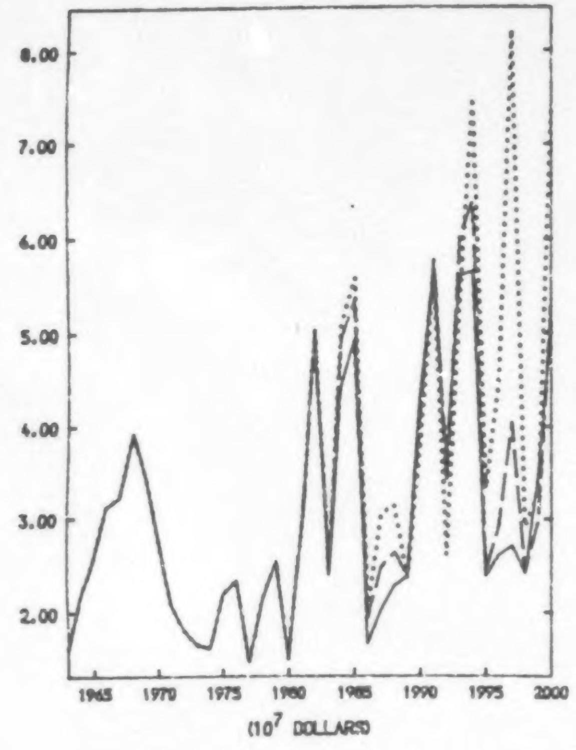
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



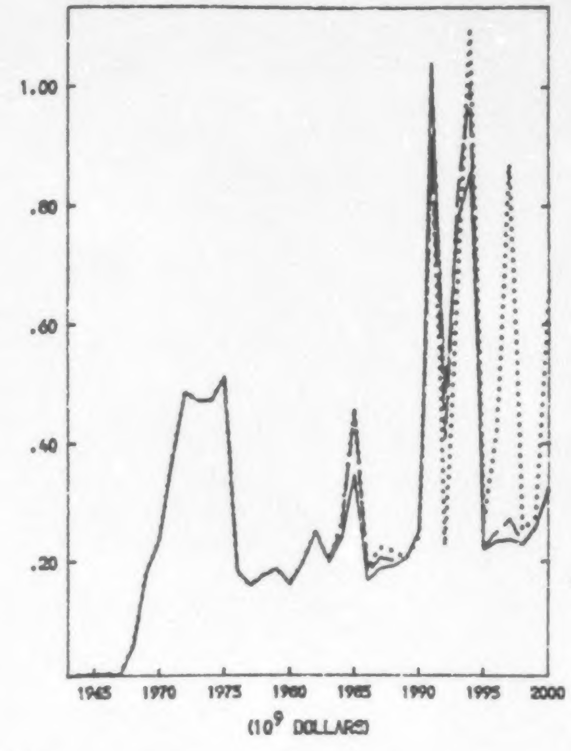
23-PAPER AND ALLIED PROD. EXC CONTAINERS



24-PAPERBOARD CONTAINERS AND BOXES

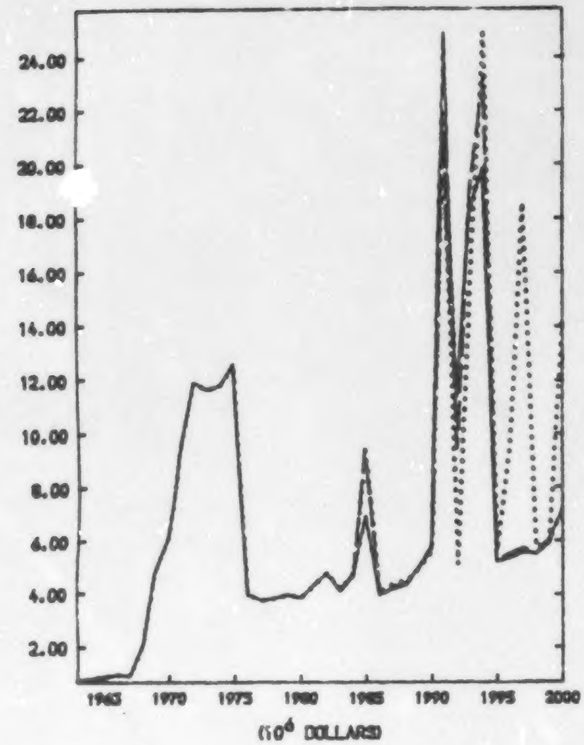


25-PRINTING AND PUBLISHING

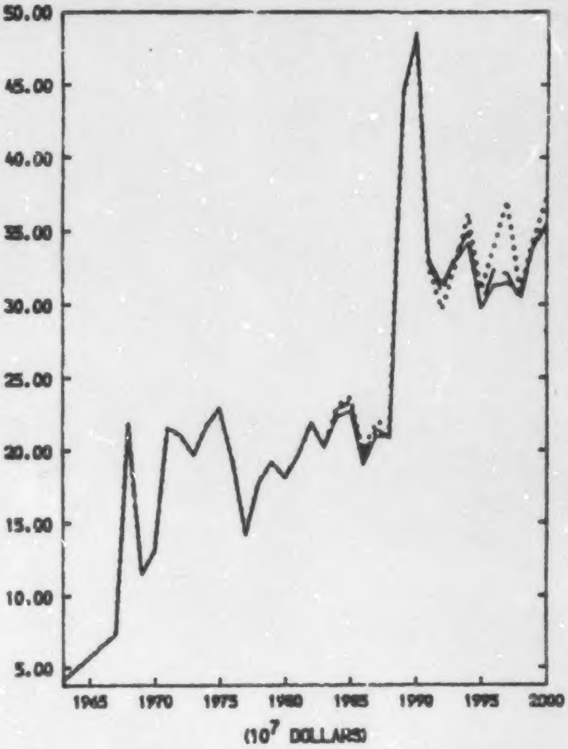


26-CHEMICALS AND SELECTED CHEM PRODUCTS

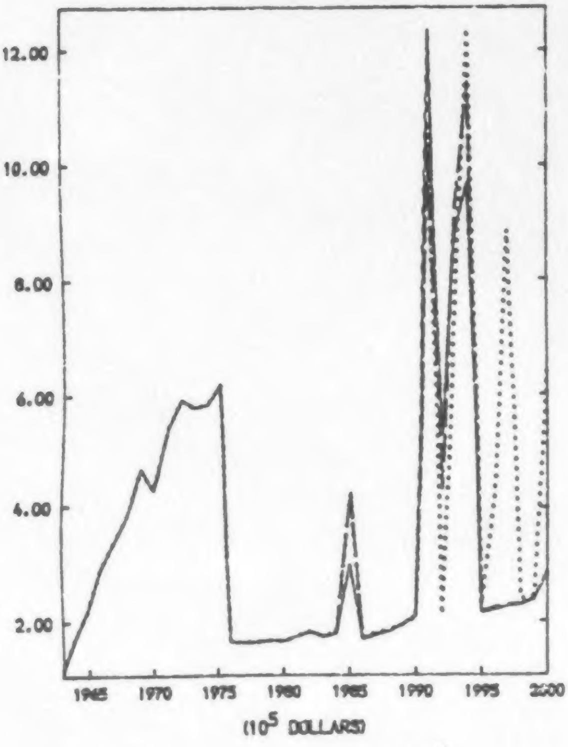
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



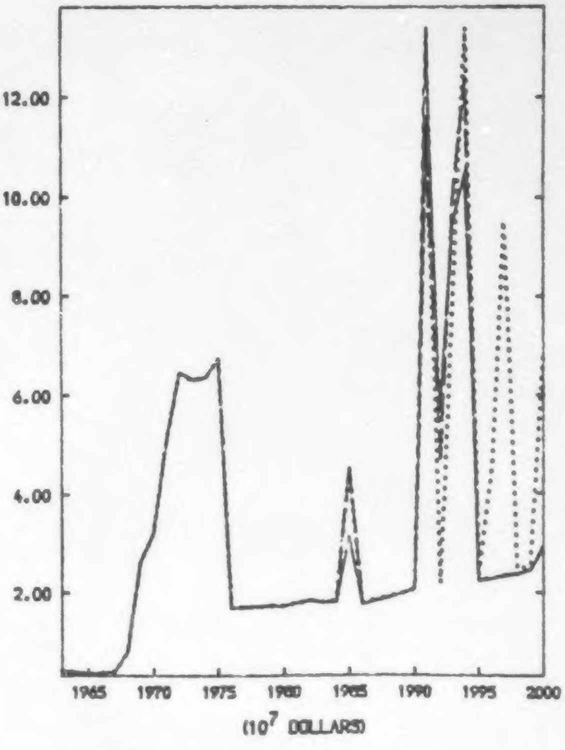
27-PLASTICS AND SYNTHETIC MATERIALS



28-DRUGS,CLEANING AND TOILET PREPARATION

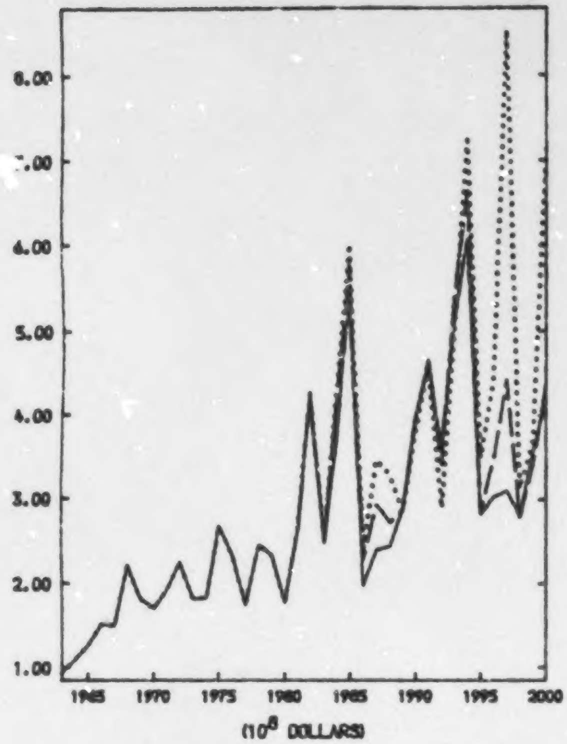


29-PAINTS AND ALLIED PRODUCTS

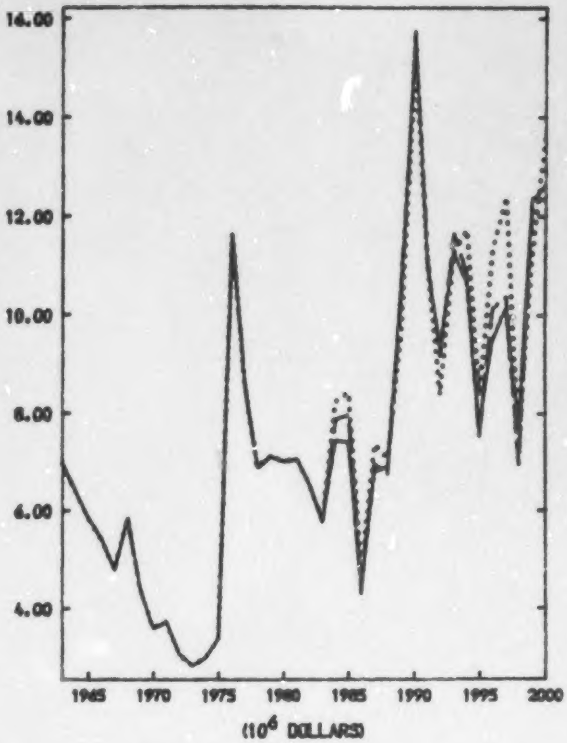


30-PETROLEUM REFINING AND ALLIED IND.

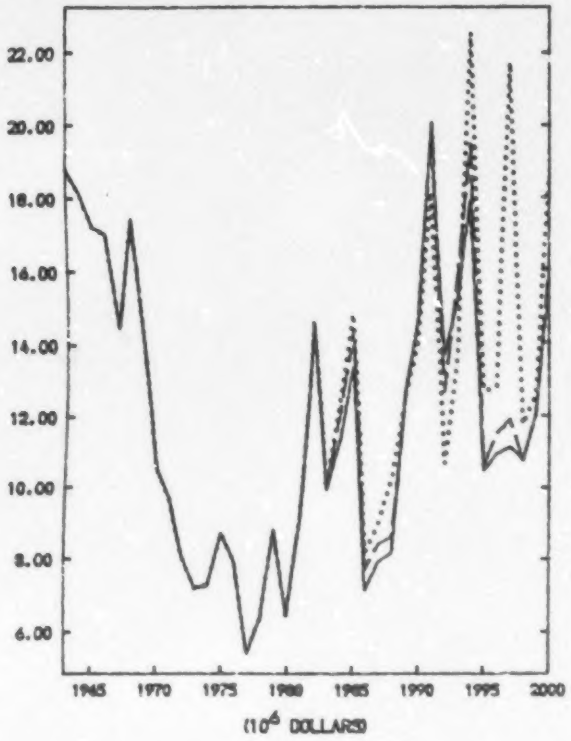
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



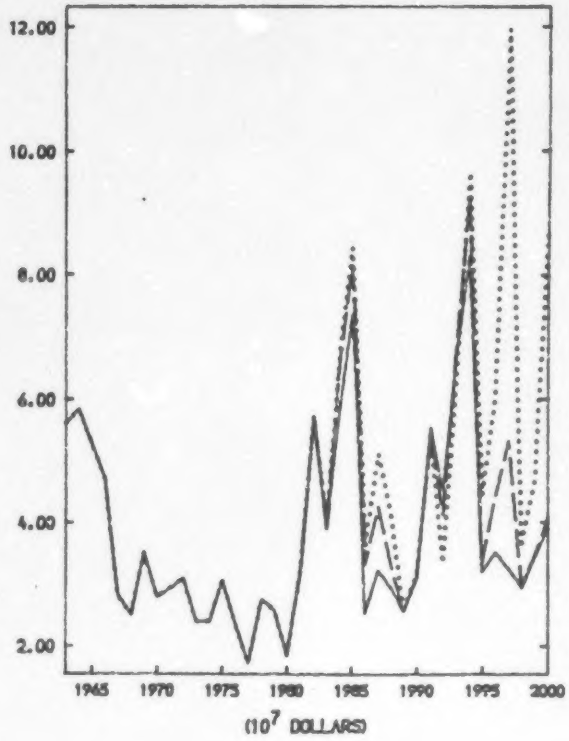
31-RUBBER AND MISC PLASTIC PRODUCTS



33-FOOTWEAR AND OTHER LEATHER PRODUCTS

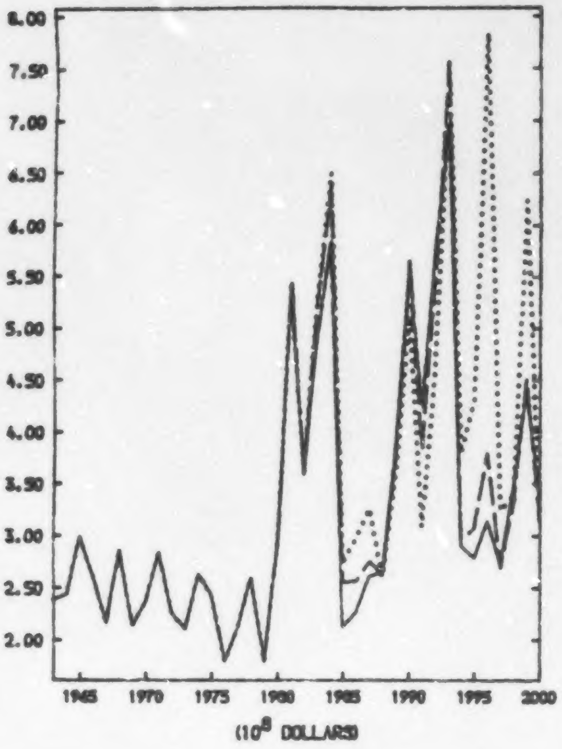


34-GLASS AND GLASS PRODUCTS

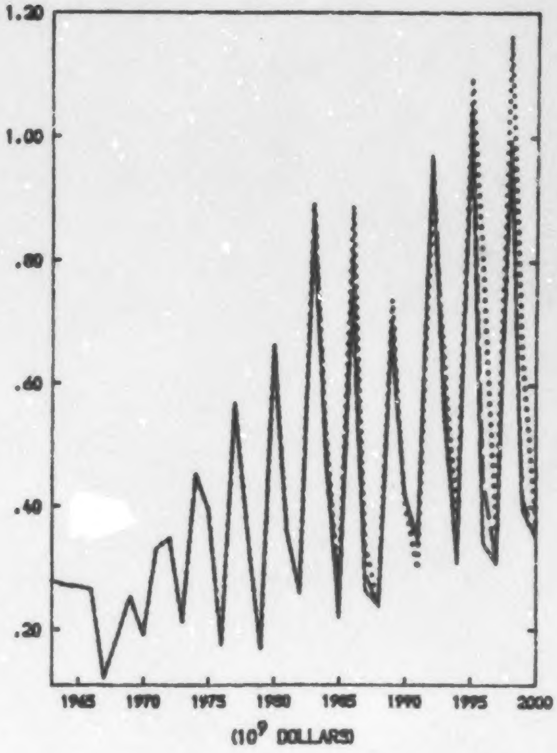


35-STONE AND CLAY PRODUCTS

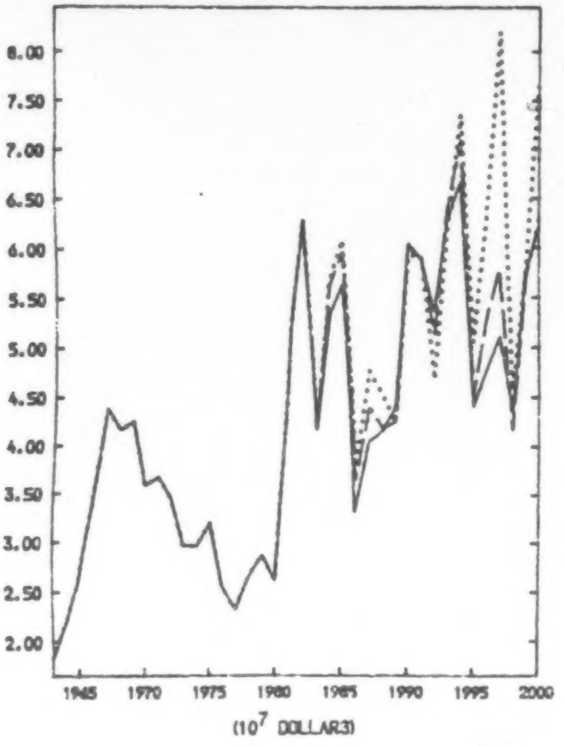
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



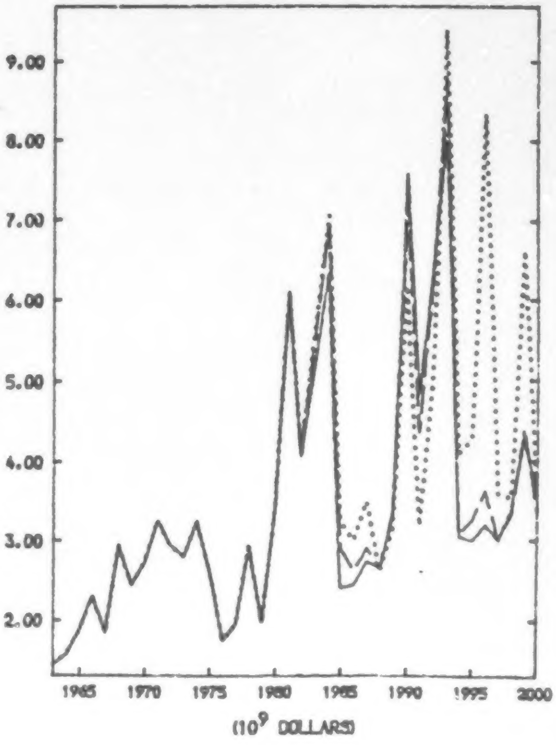
36–PRIMARY IRON AND STEEL MANUFACTURING



37–PRIMARY NONFERROUS METALS MANUFACTURE

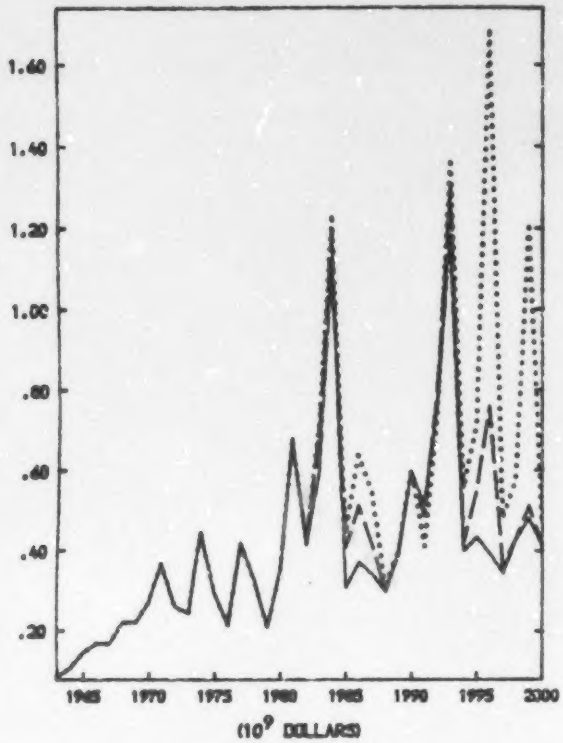


38–METAL CONTAINERS

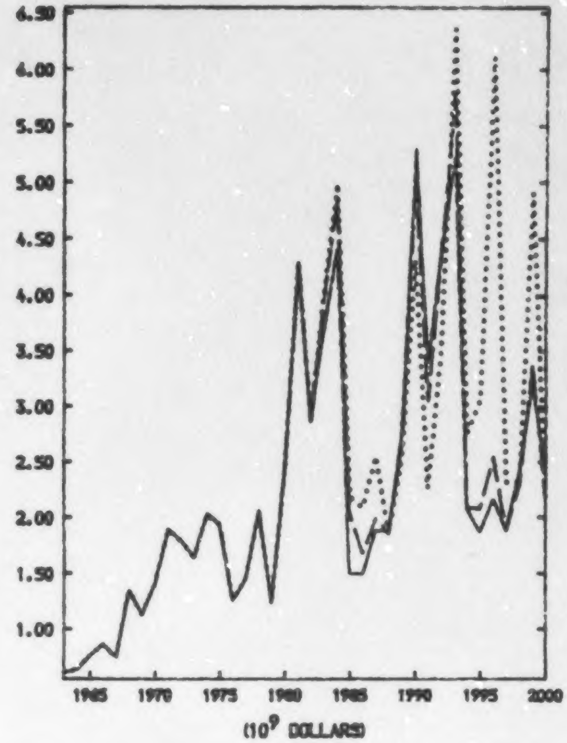


39–HEATING, PLUMBING, OTHER METAL PRODUCTS

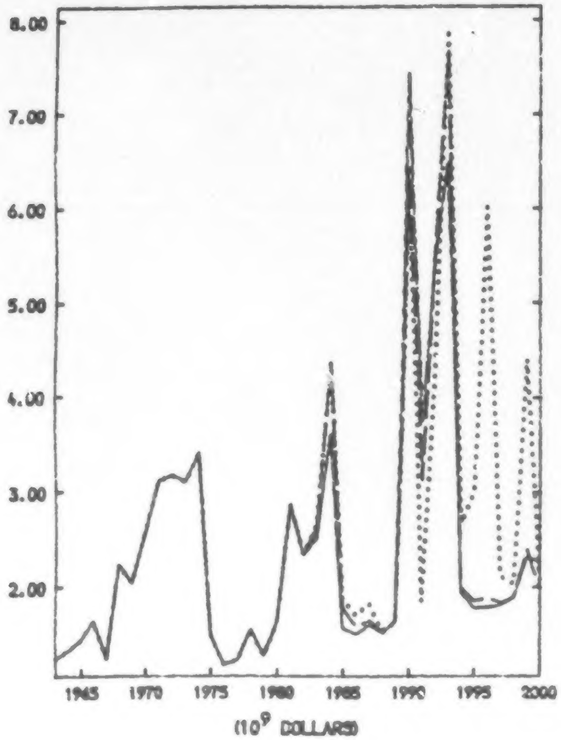
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



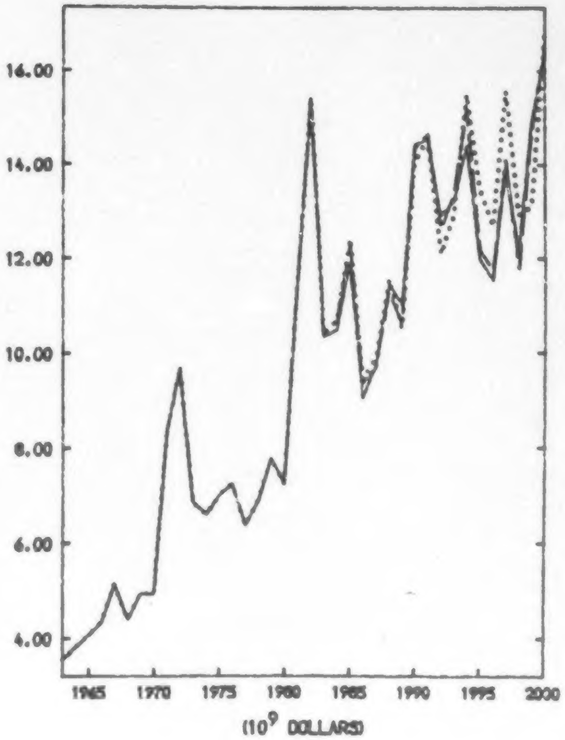
40-SCREW MACHINE PRODUCTS AND STAMPINGS



41-OTHER FABRICATED METAL PRODUCTS

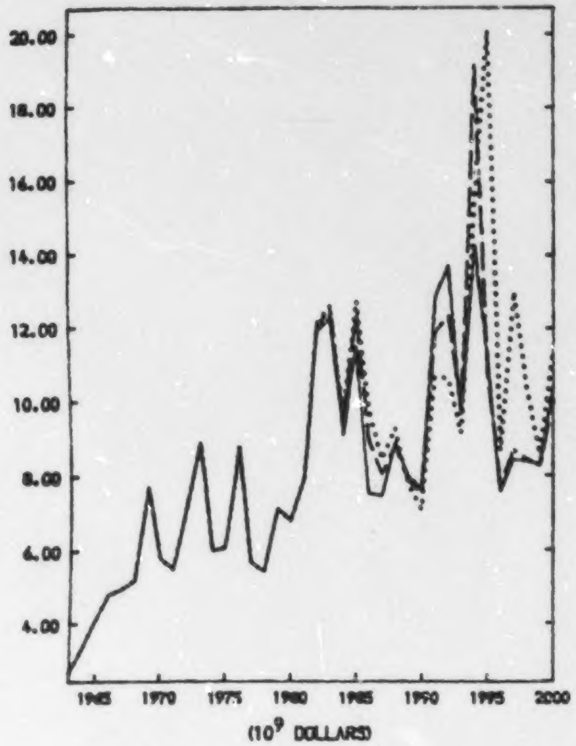


42-ENGINES AND TURBINES

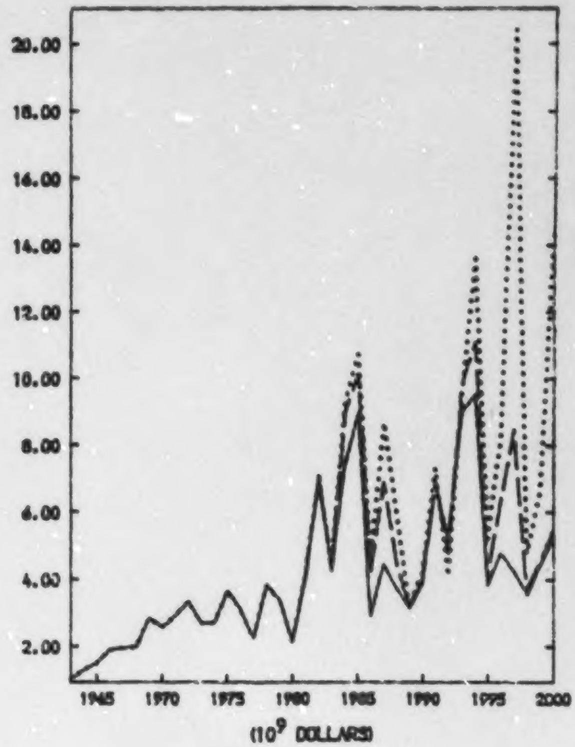


43-FARM AND GARDEN MACHINERY

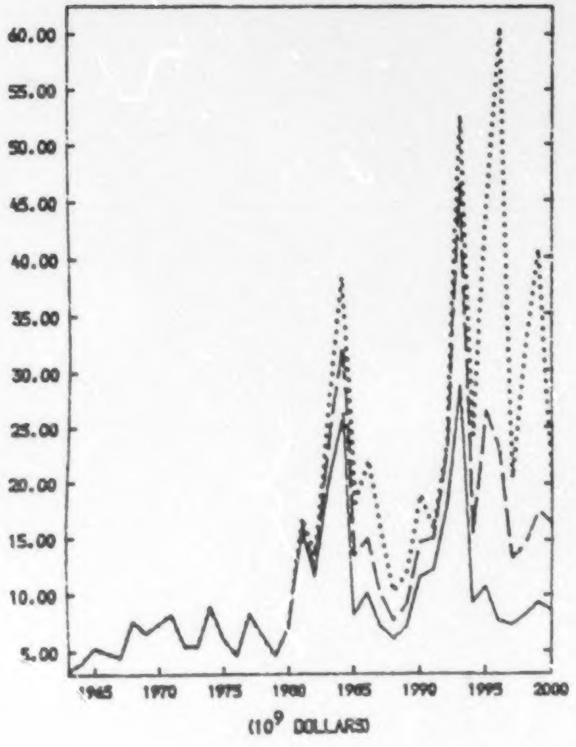
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



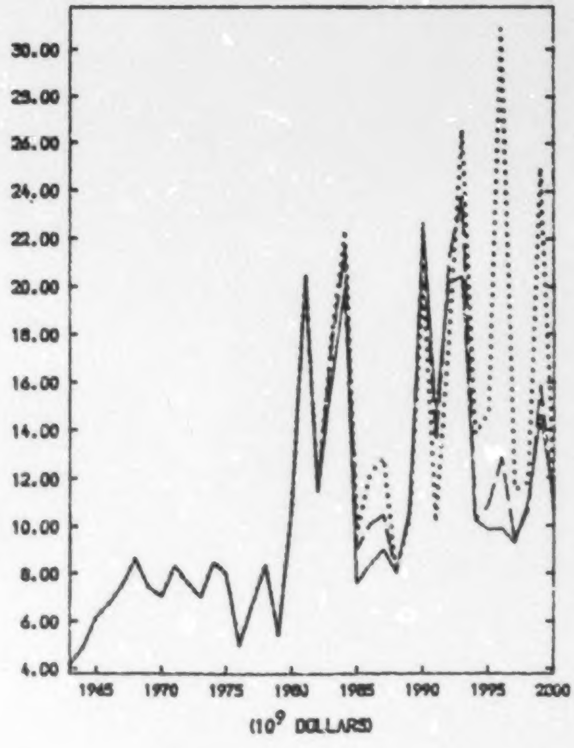
44–CONSTRUCTION AND MINING MACHINERY



45–MATERIALS HANDLING EQUIPMENT

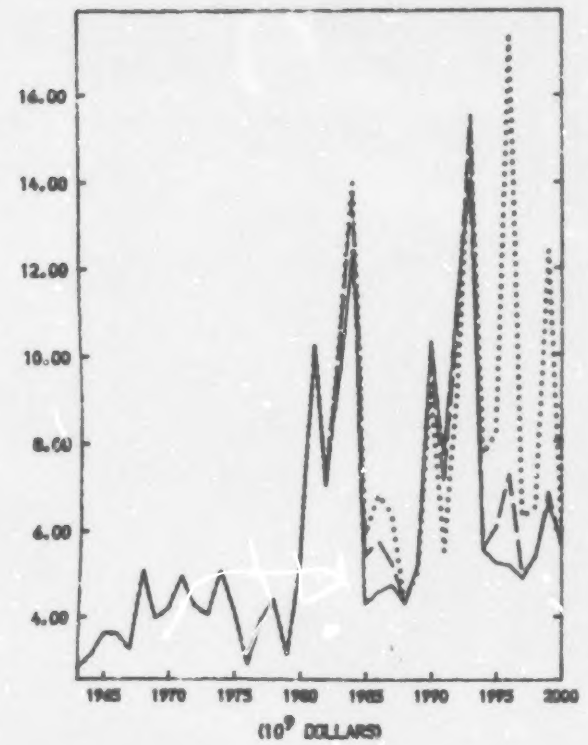


46–METALWORKING MACHINERY AND EQUIPMENT

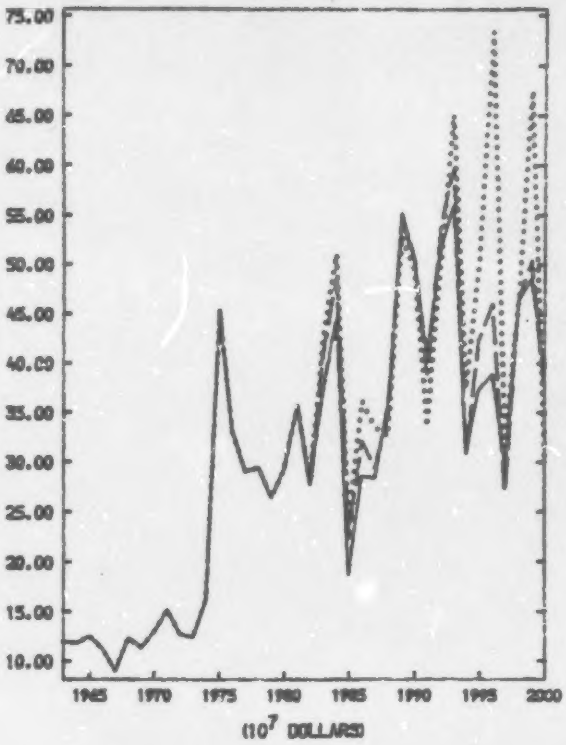


47–SPECIAL INDUSTRY EQUIPMENT

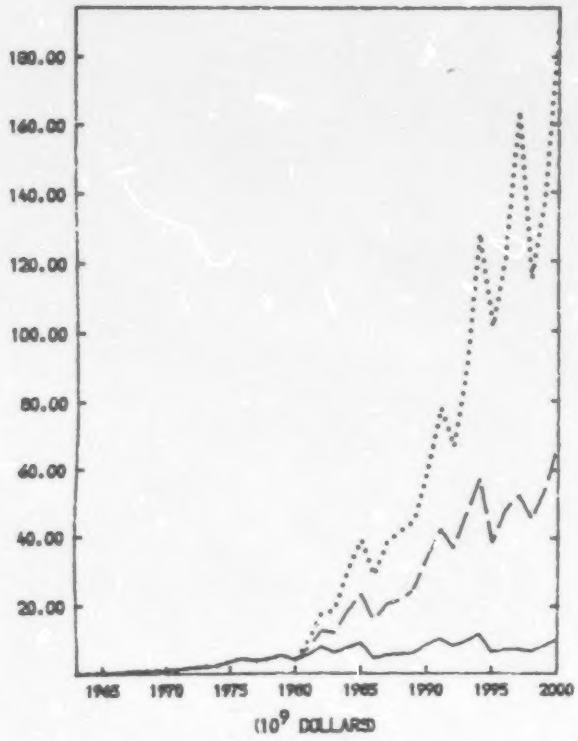
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



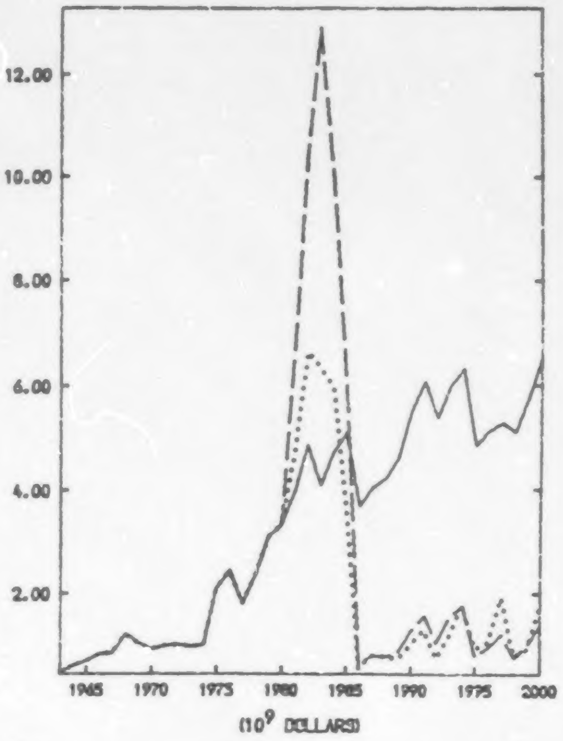
48-GENERAL INDUSTRIAL EQUIPMENT



49-MISC MACHINERY, EXCEPT ELECTRICAL

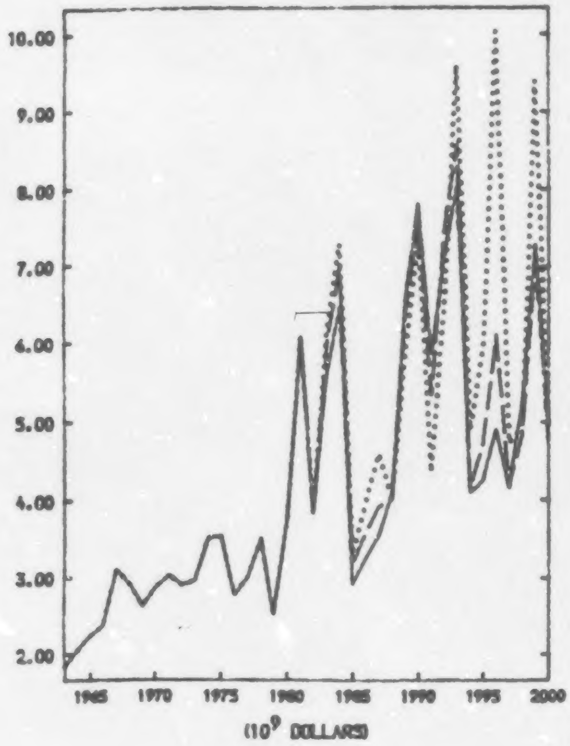


50-ELECTRONIC COMPUTING EQUIPMENT

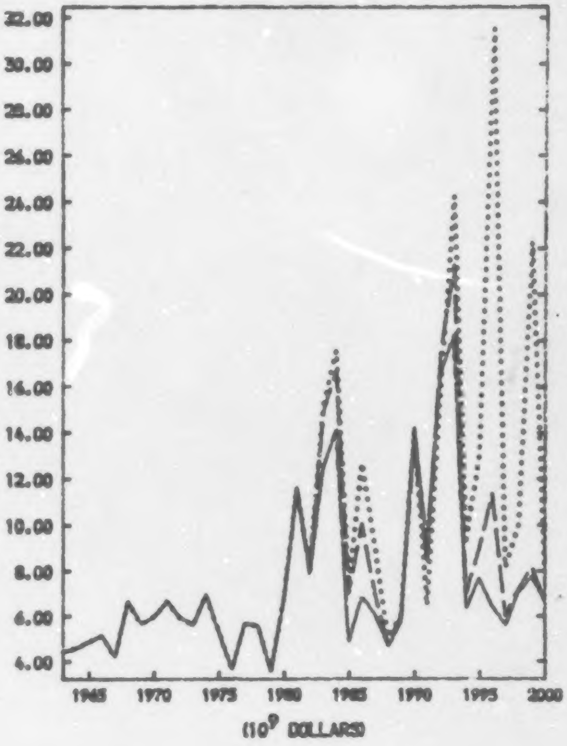


51-OFFICE MACHINES, EXCEPT COMPUTERS

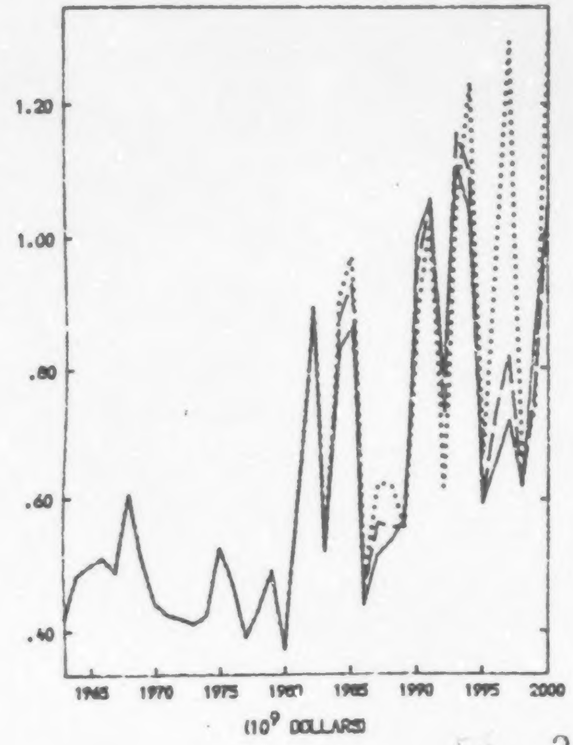
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



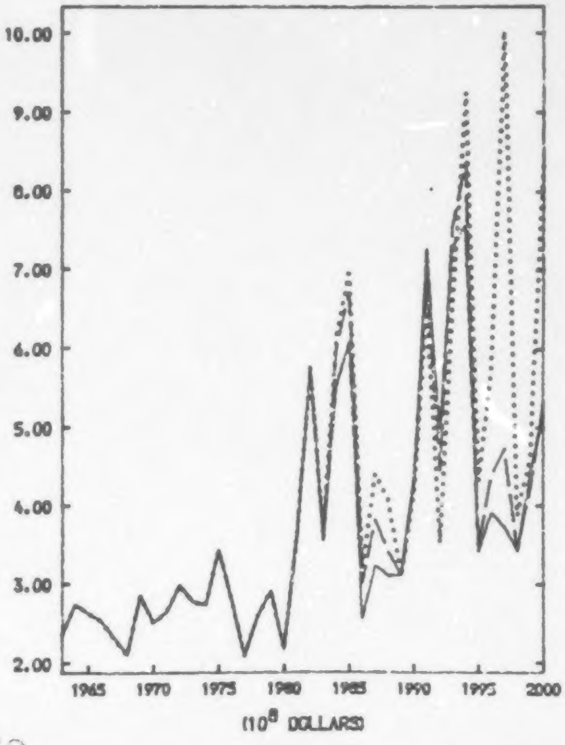
52-SERVICE INDUSTRY MACHINES



53-ELECTRIC INDUSTRIAL EQUIPMENT

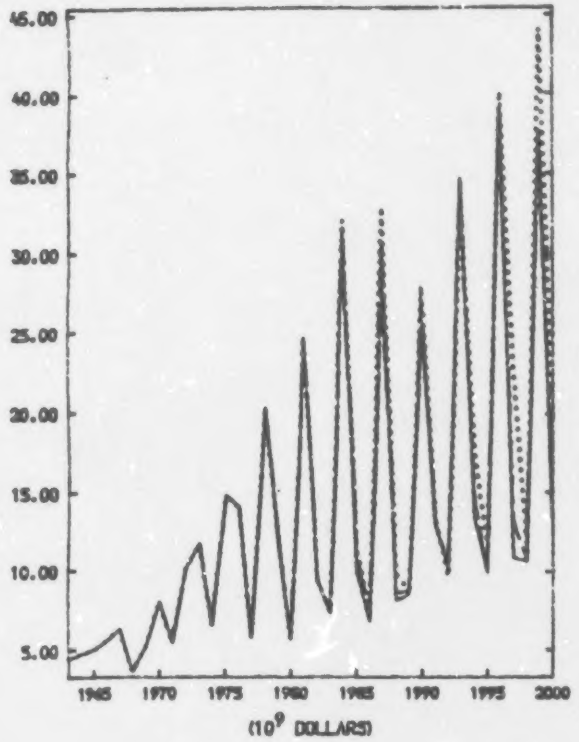


54-HOUSEHOLD APPLIANCES

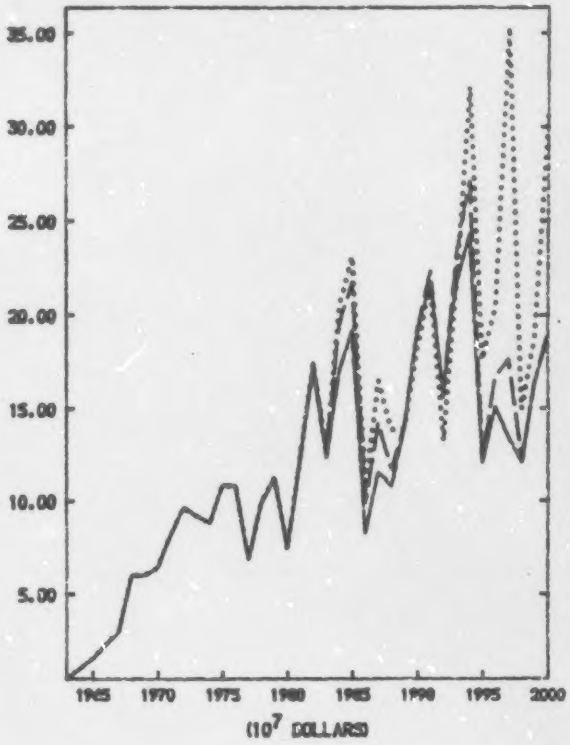


55-ELECTRIC LIGHTING AND WIRING EQUIP.

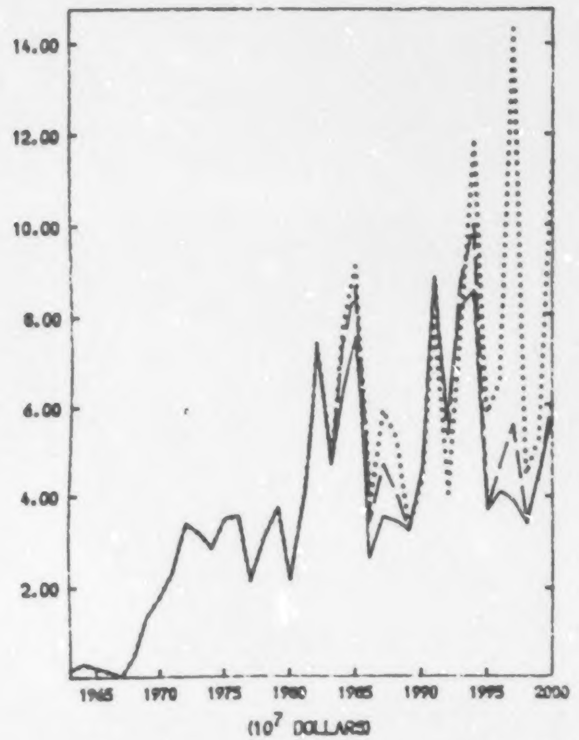
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



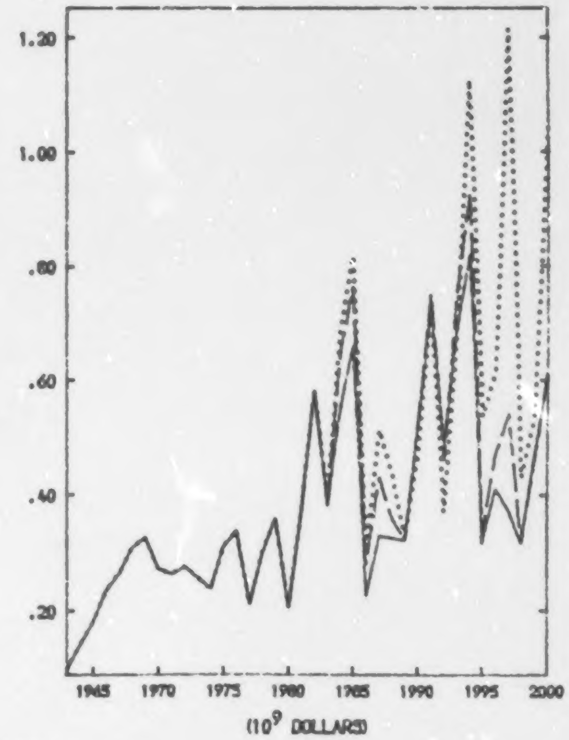
56-RADIO,TV AND COMMUNICATIONS EQUIPMENT



57-ELECTRON TUBES

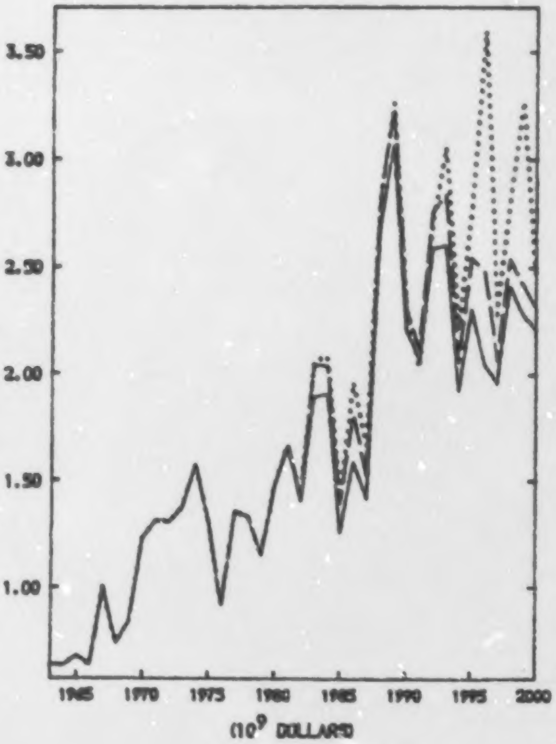


58-SEMICONDUCTORS AND RELATED DEVICES

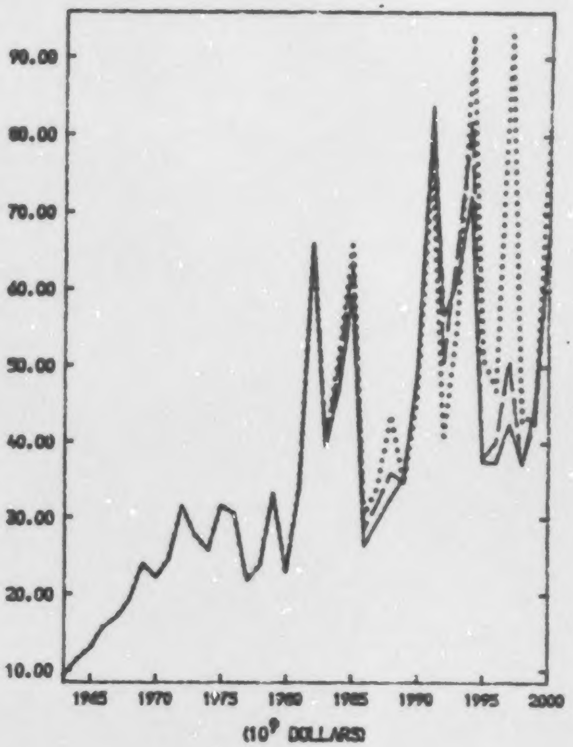


59-ELECTRONIC COMPONENTS, NEC

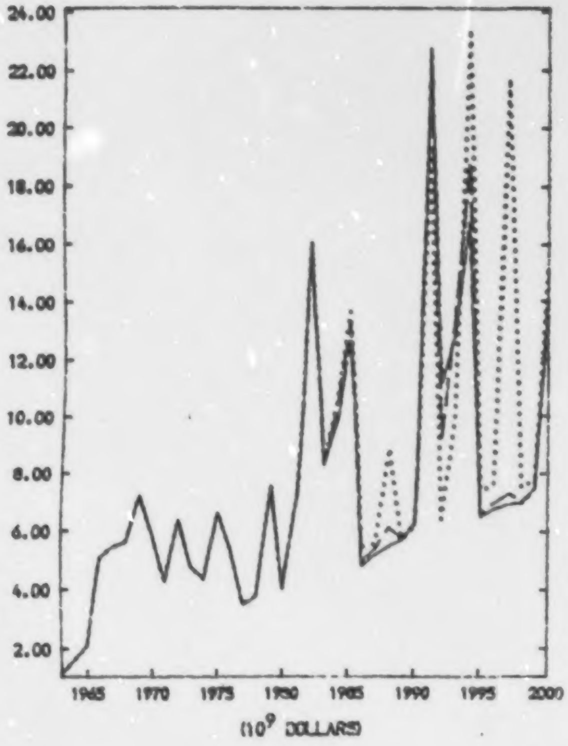
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



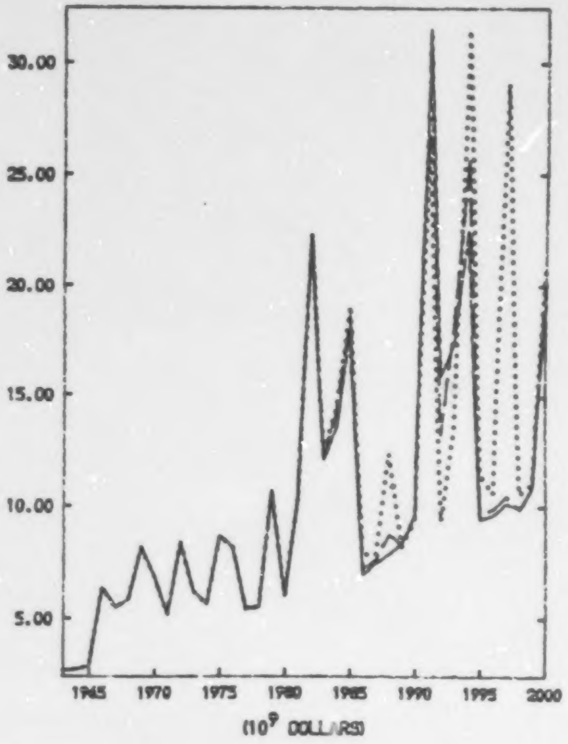
60-MISC ELECTRIC. MACHINERY AND SUPPLIES



61-MOTOR VEHICLES AND EQUIPMENT

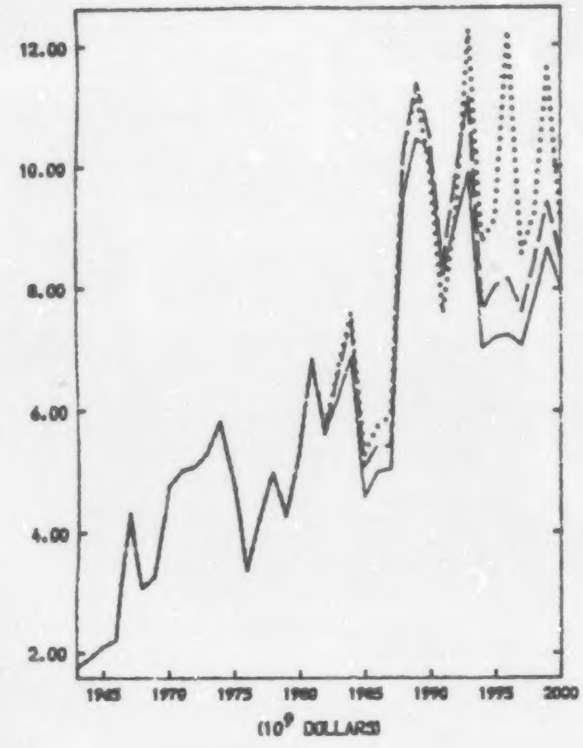


62-AIRCRAFT AND PARTS

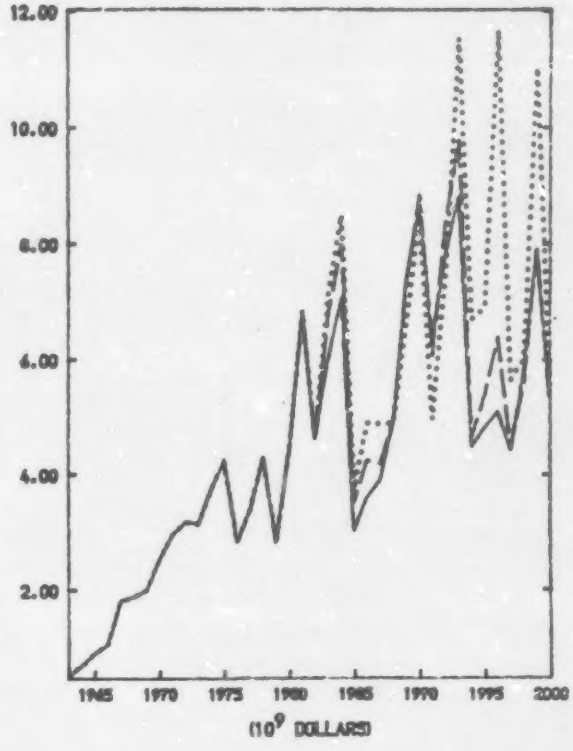


63-OTHER TRANSPORTATION EQUIPMENT

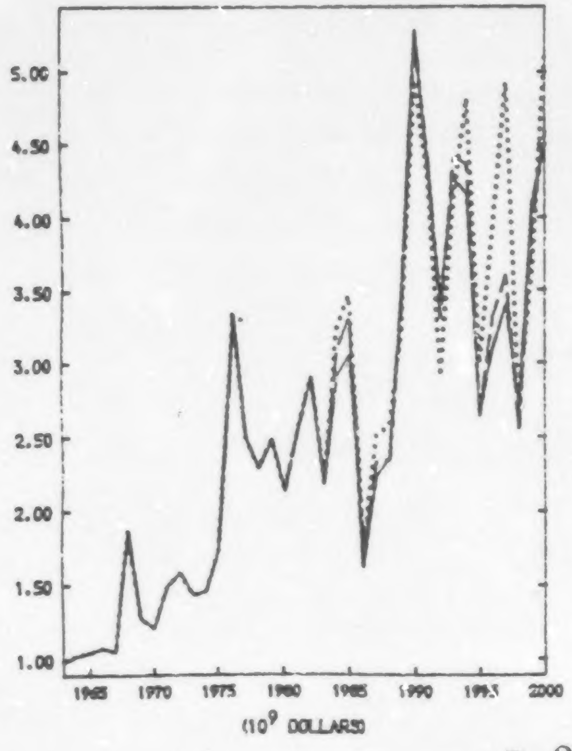
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



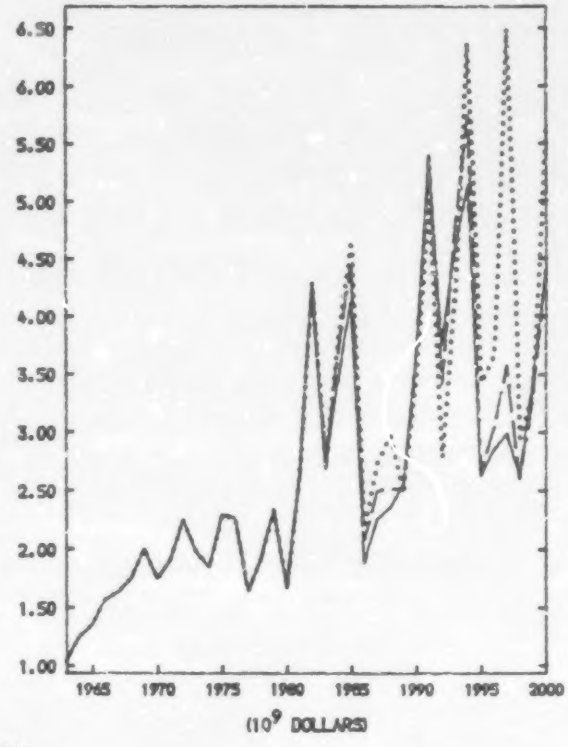
64-SCIENTIFIC AND CONTROL INSTRUMENTS



65-OPTICAL AND PHOTOGRAPHIC EQUIPMENT

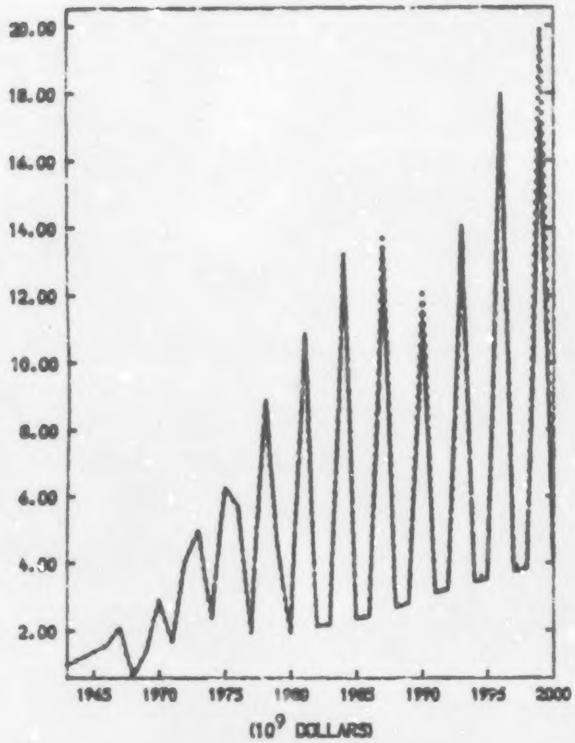


66-MISCELLANEOUS MANUFACTURING

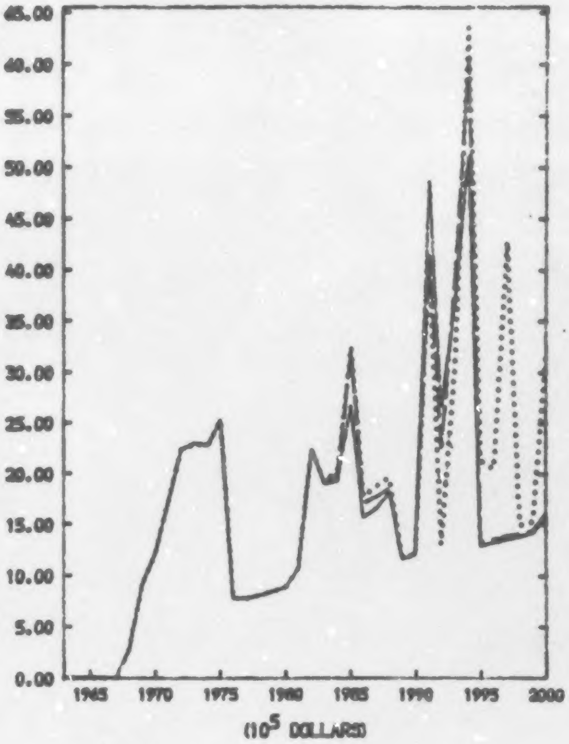


67-TRANSPORTATION AND WAREHOUSING

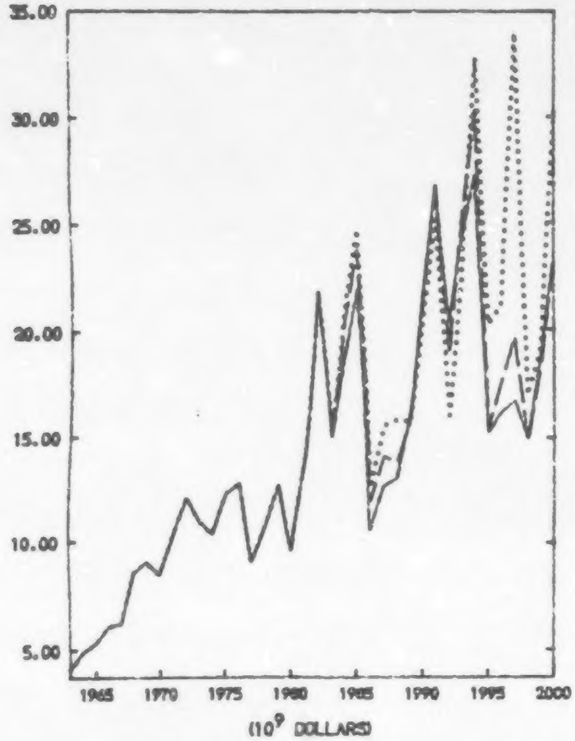
E. PRODUCTION OF INVESTMENT GOODS BY SECTOR



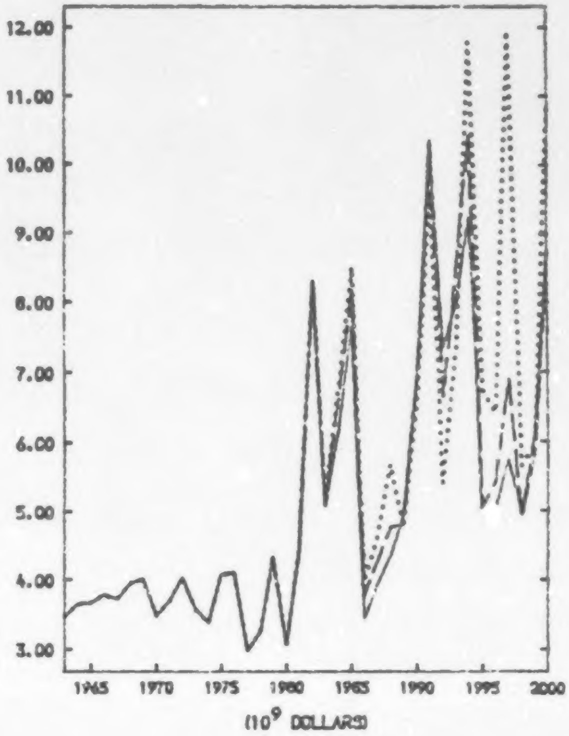
68-COMMUNICATIONS, EXCEPT RADIO AND TV



70-ELECTRIC, GAS AND WATER SERVICES



71-WHOLESALE TRADE



72-RETAIL TRADE